ESSENTIALS OF BIOLOGY

GEORGE W. HUNTER

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A Balanced Aquarium. The fish and other animals give off carbon dioxide and nitrogenous wastes which, under certain conditions, are used by the green plants for the manufacture of food and living matter. The plants give off oxygen as a by-product during starch-making, and their bodies may be used as food by the animals.

ESSENTIALS OF BIOLOGY

PRESENTED IN PROBLEMS

BY

GEORGE WILLIAM HUNTER, PH.D.

PROFESSOR OF BIOLOGY, KNOX COLLEGE, GALESBURG, ILLINOIS;
FORMERLY HEAD OF THE DEPARTMENT OF BIOLOGY,
DE WITT CLINTON HIGH SCHOOL, NEW YORK

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W. P. 29

THE PLAN AND PURPOSE OF THIS BOOK

THE plan of this book recognizes first-year biology as a *science* founded upon certain underlying and basic principles. These principles underlie not only biology, but also organized society. The culmination of such an elementary course is avowedly the understanding of man, and the principles which hold together such a course should be chiefly *physiological.* The functions of all living things, plant or animal, movement, irritability, nutrition, respiration, excretion, and reproduction; the interrelation of plants and animals and their economic relations, all these as they relate to man should enter into a course in elementary biology.

But to make plain these physiological processes, difficult even for an advanced student of biology to comprehend, the simplest method of demonstration is necessary. Plant physiology, because of the ease with which simple demonstrations can be made, is more profitable ground for beginners than is the physiology of animals. The foods which animals use are manufactured and used by green plants; the action of the digestive enzymes, the principle of osmosis, and the subject of reproduction can better be first handled from the botanical aspect. The topics just mentioned introduced from the standpoint of the botanist gain much by repetition from the zoölogical angle. The principles of physiology, after being applied in experiment to plants and animals, emerge in final clarity when applied at the last to man, — the most complex of all living things.

One of the most important factors in successful science teaching is repetition. In a recent address President Remsen of Johns Hopkins University said: —

"The most important defect in the teaching of chemistry to-day is the absence of repetition. There are too many fleeting impressions. We cover too much ground. The student gets only a veneer."

What is true of chemistry is equally true of biological science. We spend too much time in teaching unessentials taken from our immense field, and we do not spend enough time in emphasizing from constantly varied points of attack the *fundamental truths* on which the science of biology is built. The pages which follow are an attempt to drive home by repetition, and from many points of view, some of the important principles of physiological biology.

One sufficient reason for the placing of a course in biology in the first year of the secondary course lies in the fact that at this time the child is receptive to the message of applied biology. Private and public hygiene, the message of protective medicine and sanitation, the story of pure milk and of pure water and what they mean to a community; all these things can most logically be presented in a course that makes man the center. The allied topics of conservation of plant and animal life, the destruction of harmful plants and animals, the relation of insects and other animals to the spread of disease, and the work of civic and government departments in the development of nature's gifts and in the preservation of national health should be treated in their relation to man.

Moreover, the data given should be treated from the *biological* standpoint, not that of botany, zoölogy, or human physiology. Ideally, we might take up general principles and draw from the great storehouses of plant, animal, and human biology to illustrate each principle before going on to the next. Practically, however, such a plan does not seem to be workable, partly because of the difficulty of collecting enough material to make such demonstrations possible. It is impracticable with immature students, because they cannot grasp the many-sidedness of the application at once. This will only come after *repetition* of the principle, each time from a slightly different point of view.

It frequently happens that the related study of plants and animals may be taken up to advantage. Insects and flowers, both plentiful in the fall, may well be studied together for the relation of life habits and adaptations in the insect to cross-pollination of flowers. Applied biology, in its relation to plants or to animals, must of course be treated from all sides. The fungi and the bacteria in their relations to man are conspicuous examples.

The following chapters present such a course as has been outlined above. Beginning with a brief treatment of the constitution of the environment of plants and animals, it is shown that both animals and plants take certain materials from their surroundings, and that they may be profoundly modified by the factors in their environment. The flower and fruit, together with the related topic of insects in their relation to flowers, are taken up in the fall when material is abundant. Reproduction and the survival of certain plants because of their adaptations is the central theme. Considerable emphasis is placed on the subject of fruits useful to man, plant breeding, and other topics of economic importance. In the study of the seed and seedling, the external factors influencing growth are emphasized. The little plant within the seed is seen to be a living organism that breathes, feeds, and grows. Roots are shown to be absorbing organs, the method of osmosis being explained in detail. The subject of soils and the relation of bacteria to crop rotation is taken up at this point. A discussion of the stem introduces the idea of transportation of material. The leaf serves to introduce the pupil to plants as food and oxygen makers. Forestry is developed at this time, considerable emphasis being placed on the need for conservation. Then follows a discussion of plants of various forms, of the simplest of plants, and particularly with the economic relation existing between plants and animals. The lower forms of plants form an excellent introduction to the lowest animals, and the conditions existing in a balanced aquarium or a hay infusion serve as a text to show the larger relations existing between plants and animals. In the study of animal life, a number of types have been introduced, not with the idea that the pupil will take all, but that an option will be given. The best order of topics in the spring term will be : Protozoa; the Metazoa (either sponge or hydra), used to develop the concept of a collection of cells, and the physiological division of labor, worms or crustaceans, the latter to illustrate adaptations in animals; the insects for the sake of elementary classification and some general biological considerations well taken up there; and then the vertebrates. The fish may be used as a study of adaptations (in which case the crustaceans may be omitted), and the frog, when taken at the spawning season, may be studied for its development, and as a

basis for the anatomical basis needed in the study of human physiology. Birds, reptiles, and the Mammalia are discussed from the economic standpoint, no laboratory work being required. Field work on these forms should be encouraged. The later chapters treat of man as an animal and a mammal. After a brief anatomical consideration of adaptations in the skeleton and muscles, the skin as an organ of protection and excretion, and of the functions of the nervous system, a study of foods and dietaries is begun. Then come digestion and absorption, blood and its circulation, respiration and excretion. A final chapter treats of health and disease from the standpoint of private and public hygiene.

If the work begins with the spring term, the introductory chapters may be taken, then the seed and seedling, root, stem, leaf, flower, and fruit, reserving the treatment of the cell, simple plants, and the bacteria until the end of the term. This allows taking up the thread in the fall where it was dropped, with an introduction through the balanced aquarium and the hay infusion to the relations existing between plants and animals. The best order of topics in the fall seems to be : protozoa, some simple metazoan, insects (taken while living insects may still be obtained), then such other groups of invertebrates as desired, the year's work again culminating with the vertebrates and biology as applied to the human animal.

The courses as outlined above are held together and made continuous by certain biological ideas and ideals, which are kept before the pupil from the beginning to the end of the course. Man is the center of the course, and at the last the illustrations are applied to the human mechanism.

This plan includes the solving of a number of problems in biology, each of which is more or less determined by the one immediately preceding it. So far as possible, the problems have a human interest. Abstractions are not part of the thought of a first-year pupil. Concrete problems, related when possible to the daily life of the pupil, have been used. The problems are stated in the form of laboratory exercises or suggestions, the material for which is in the hands of the pupil or is worked out as a demonstration before the class. In all cases the laboratory types or physiological experiments demonstrate some important principle of biology.

The laboratory exercise immediately precedes the textbook discussion, the latter being used to clear up any false inferences the pupil may have made from the specimen in hand and to fix the object of the problem in the mind of the pupil. Too often has a laboratory exercise meant nothing to a pupil but "busy work." A plainly outlined and organized plan of attack, a few references to the text or to previous work performed, and a definite problem will result in better and more definite laboratory work. For use with this book a manual for the solution of laboratory problems has been prepared by my coworker, Mr. R. W. Sharpe. The problems to be solved with the aid of the manual are in boldface italics. It is neither expected nor desirable that a pupil take all of the problems so indicated in a year's course.

Two styles of type have been used in the text. The larger type contains material which is believed to be of first importance, the smaller type the less important topics. The manuscript was read in its entirety by Professor H. E. Walter of Brown University. To him I owe sincere thanks for many helpful criticisms and suggestions.

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extracts from his excellent article in *School Science* on the effects of Alcohol. R. W. Coryell and J. W. Tietz, two of my former pupils, made several of the photographs of experiments.

At the end of each of the following chapters is a list of books which have proved their use either as reference reading for students or as aids to the teacher. Most of the books mentioned are within the means of the small school. Two sets are expensive: one, *The Natural History of Plants*, by Kerner, translated by Oliver, published by Henry Holt and Company, in two volumes, at $11; the other, *Plant Geography upon a Physiological Basis*, by Schimper, published by the Clarendon Press, $12; but both works are invaluable for reference.

For a general introduction to physiological biology, Parker, *Elementary Biology*, The Macmillan Company; Sedgwick and Wilson, *General Biology*, Henry Holt and Company; and Verworn, *General Physiology*, The Macmillan Company, are most useful and inspiring books.

Two books stand out from the pedagogical standpoint as by far the most helpful of their kind on the market. No teacher of botany or zoölogy can afford to be without them. They are: Lloyd and Bigelow, *The Teaching of Biology*, Longmans, Green, and Company, and C. F. Hodge, *Nature Study and Life*, Ginn and Company. Other books of value from the teacher's standpoint are: Ganong, *The Teaching Botanist*, The Macmillan Company; L. H. Bailey, *The Nature Study Idea*, Doubleday, Page, and Company, and McMurry's *How to Study*, Houghton, Mifflin Company.

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I. SOME REASONS FOR THE STUDY OF BIOLOGY

What is Biology? — *Biology is the study of living beings, both plant and animal.* Inasmuch as man is an animal, the study of biology includes the study of man in his relations to the plants and the animals which surround him. Most important of all is that branch of biology which treats of the mechanism we call the human body, — of its parts and their uses, and its repair. This subject we call *human physiology.*

Why study Biology? — Although biology is a very modern science, it has found its way into most high schools; and an increasingly large number of boys and girls are yearly engaged in its study. The question might well be asked by any of these students, Why do I take up the study of biology? Of what practical value is it to me? Aside from the discipline it gives me, is there anything that I can take away which will help me in my future life as a boy or girl with only a high school education?

Human Physiology. — The answer to this question is plain. If the study of biology will give us a better understanding of our own bodies and their care, then it certainly is of use to us. That phase of biology known as *physiology* deals with the uses of the parts of a plant or animal; human physiology and hygiene deal with the uses and care of the parts of the human animal. The prevention of sickness is due in a large part to the study of hygiene. It is estimated that 400,000 out of the 1,600,000 deaths that occur yearly in this country could be averted if only *all* people lived in a hygienic manner. In its application to the lives of each of us, as a member of our family, as a member of the school we attend, and as a future citizen, a knowledge of hygiene is of the greatest importance.

Relations of Plants to Animals. — But there are other reasons why an educated person should know something about biology. We do not always realize that if it were not for the green plants, there would be no animals on the earth. Green plants furnish

animals with their food. Even the meat-eating animals feed in the long run upon those that feed upon plants. How the plants manufacture this food and the relation they have to animals will be discussed in later chapters. Plants furnish man with the greater part of his food in the form of grains and cereals, fruits and nuts, edible roots and leaves; they provide his domesticated animals with food; they give him timber for his houses and wood and coal for his fires; they provide him with pulp wood, from which he makes his paper, and oak galls, from which he obtains ink. Much of man's clothing and the thread with which they are sewed together come from fiber-producing plants. Most medicines, beverages, flavoring extracts, and spices are plant products, while plants are made use of in hundreds of ways in the useful arts and trades, producing varnishes, dyestuffs, rubber, and other useful products.

Bacteria in their Relation to Man. — In still another way, certain plants vitally affect mankind. These tiny plants, so small that millions can exist in a single drop of fluid, are called *bacteria* or *germs*. Existing almost everywhere about us, — in water, soil, food, and the air, — they play a tremendous part in shaping the destiny of man on the earth. They help him in that they act as scavengers, causing things to decay; they help make cheese and butter; they assist the tanner; and the farmer could not do without them; but they likewise spoil our meat and fish, and our vegetables and fruits; they sour our milk, and make our canned goods spoil. More than this, they cause diseases, among others tuberculosis, a disease so harmful as to be called the "white plague." Fully one half of all yearly deaths are caused by these plants. So important are the bacteria that a subdivision of biology, called *bacteriology*, has been named after them, and hundreds of scientists are devoting their lives to the study of germs and their control. The greatest of all bacteriologists, Louis Pasteur, once said, "It is within the power of man to cause all parasitic diseases (diseases mostly caused by bacteria) to disappear from the world." His prophecy is gradually being fulfilled, and it may be the lot of some boys or girls who read this book to do their share in helping to bring this condition of affairs about.

Harmful Relation of Animals to Man. — Animals play an im-

portant part in the world in causing and carrying disease. Animals that cause disease are usually tiny, and live upon other animals as parasites; that is, they get their living from their hosts on which they feed. Among the diseases caused by parasitic animals are malaria, yellow fever, the sleeping sickness, and hookworm disease. Animals also *carry* disease, especially the flies and mosquitoes; rats and other animals are also well known as spreaders of disease.

From a money standpoint, animals called insects do much harm. It is estimated that in this country alone they are annually responsible for $800,000,000 worth of damage.

The Uses of Animals to Man. — We all know the uses man has made of the domesticated animals for food and as beasts of burden. But many other uses are found for animal products, and materials made from animals. Wool, furs, leather, hides, feathers, and silk are examples. The arts make use of ivory, tortoise shell, corals, and mother of pearl; from animals come perfumes and oils, glue, lard, and butter; animals produce honey, wax, milk, eggs, and various other commodities.

The Conservation of our Natural Resources. — Still another reason why we should study biology is that we may work understandingly for the conservation of our natural resources, especially our forests. The forest, aside from its beauty and its health-giving properties, holds water in the earth. It keeps the water from drying out of the earth on hot days and from running off on rainy days. Thus a more even supply of water is given to our rivers, and thus freshets are prevented. Countries that have been deforested, such as China, Italy, and parts of France, are now subject to floods, and are in many places barren. On the forests depend our timber, our future water power, and the future commercial importance of cities which, like New York, are located at the mouths of our navigable rivers.

Plants and Animals mutually Helpful. — The study of biology also shows us the interrelation existing between plants and animals on the earth. Most plants and animals stand in an attitude of mutual helpfulness to one another, plants providing food and shelter for animals; animals giving off waste materials useful to plants in the making of food. We also learn that plants and

animals need the same conditions in their surroundings in order to live: water, air, food, a favorable temperature, and usually light. We learn that the life processes of both plants and animals are essentially the same, and that the living matter of a tree is as much alive as is the living matter in a fish, a dog, or a man.

Biology in its Relation to Society. — Finally, the study of biology should be part of the education of every boy and girl, because society itself is founded upon the principles which biology teaches. Plants and animals are living things, each taking what it can from its surroundings; they enter into competition with one another, and those which are the best fitted for life outstrip the others. Health and strength of body and mind are factors which tell in winning. The strong may hand down to their offspring the characteristics which make them the winners.

Man has made use of this message of nature, and has developed improved breeds of horses, cattle, and other domestic animals. Plant breeders have likewise selected the plants or seeds that have varied toward better plants and thus have stocked the earth with hardier and more fruitful domesticated plants. Man's dominion over the living things of the earth is tremendous. It is due to the understanding of the principles which underlie the science of biology.

II. THE SURROUNDINGS OR ENVIRONMENT OF LIVING THINGS

Environment. — A plant or an animal living on the earth may be said to come in contact with air, water, and soil. It may be influenced by light, varying conditions of temperature, of the atmosphere or water, the presence or absence of food materials, and some other things. We shall later see that the sum total of these various factors, acting upon the living thing, may cause great changes to take place in the structure or habits of a plant or animal. The surrounding forces which act upon living things form their *environment.*

In order better to understand what a living plant or animal takes from its environment, we must find out something about the air, water, and the soil, for it is with these factors that the plant and the animal are in immediate contact.

Problem I. *A study of the common elements in the environment of living things.* (*Laboratory Manual, Prob. I.*)[1]

(*a*) *Nitrogen.*

(*b*) *Oxygen and oxidation.*

(*c*) *Hydrogen.*

(*d*) *Carbon and carbon dioxide.*

The Composition of the Air. — If we invert a large bell jar over a deep tray containing water, having previously placed a float holding a bit of burning phosphorus upon the surface of the water, we find that as the phosphorus burns, the water slowly rises in the jar. After a little the phosphorus goes out. The water now displaces a volume equal to about one fifth of the

Experiment to show the amount of nitrogen present in the air.

[1] Sharpe, *A Laboratory Manual for the Solution of Problems in Biology*, American Book Company.

space occupied by the air in the jar. When the water reaches this height, it goes no higher, and, no matter how many times the experiment is repeated, the phosphorus invariably goes out when the water displaces one fifth of the air in the jar.

Evidently, the burning of the phosphorus uses up some gas within the jar, which supports the flame, and the gas which remains in the jar, occupying about four fifths of the space, does not have the power of maintaining the flame. The former gas is called oxygen; the latter, nitrogen. These two gases form the principal constituents of the air in the proportion seen in the experiment.

Chemical Elements. — All the materials of this universe, both living and lifeless, are classified by chemists as either *chemical elements* or *chemical compounds*. A *chemical element* is a substance which has never been decomposed into anything simpler in composition. Examples of such elements are *oxygen*, making up about one fifth of the atmosphere; *nitrogen*, composing nearly all the remainder of pure air; *carbon*, an element that enters into the composition of all organic matter; and over seventy others of more or less importance to us in the study of biology.

Nitrogen. — The physical properties (those which we determine through our senses) of nitrogen are its lack of color, taste, and odor. Its chief chemical characteristics are its inability to support combustion and its slight tendency to combine with other substances. We shall later find that nitrogen is one of the most important chemical elements found in living matter. In spite of this, animals and *most* plants are absolutely unable to take any nitrogen from the air, no matter how much they may need it.

The other element in the air, oxygen, is taken out by the plants and animals. We shall be able to see how, after studying the properties of oxygen.

Preparation of Oxygen. Elements and Compounds. — Oxygen may be prepared by heating half a teaspoonful of chlorate of potash with a little less than its bulk of black oxide of manganese in a test tube over a Bunsen flame or a spirit lamp. After a moment a glowing match inserted in the mouth of a test tube bursts into a bright flame. Evidently the match burns more brightly because of the presence of a gas which has been loosed from the materials in the test tube. These materials are *chemical*

compounds; that is, chemical elements which are united by certain chemical laws to form substances called compounds. Compounds are quite different in their properties from the elements which compose them. Such is the chlorate of potash, which contains the elements oxygen, chlorine, and potassium. Heating this with oxide of manganese causes the oxygen to be released in the form of a gas. This is an example of a *chemical change.*

Preparation of Oxygen.

Properties of Oxygen. — Oxygen, when carefully prepared, is found to be colorless, odorless, and tasteless. It makes up about one fifth of the air. Combined with other substances, it forms a very large part by weight of water, rocks, minerals, and the bodies of plants and animals. Oxygen has the very important property of *uniting* with many other substances.

The chemical union of oxygen with any other substance is called oxidation. Oxidation of some sort may take place wherever oxygen is present. This fact has a far-reaching significance in the understanding of the most important problems of biology.

Oxidation in a Match. — The simple process of striking a sulphur match gives us another illustration of this process of oxidation. The head of the match is formed of a combination of phosphorus, sulphur, and some other materials. Phosphorus is a chemical element distinguished by its extreme inflammability; that is, it unites with oxygen at a comparatively low temperature, producing a flame. Sulphur is another chemical element that combines somewhat easily with oxygen but at a much higher temperature. The rest of the match head is made up of red lead, niter, or some other substance that will release oxygen, and some glue or gum to bind the materials together. The heat caused by the friction of the match head against the striking surface is enough to cause the phosphorus to ignite; this in turn

ignites the sulphur, and finally the wood of the match, composed largely of the element carbon, is lighted and oxidized. If we could take out the different chemical elements of which the match is formed and oxidize them separately, we should find that the amount of heat needed to start the oxidation of the substances would vary greatly. The element phosphorus, for example, is kept under water in a glass jar because of the extreme readiness with which it ignites in the presence of oxygen.[1]

Apparatus for separating water into the two elements hydrogen and oxygen.

Slow Oxidation. — Oxidation may take place slowly, as may be seen in the rusting of an iron nail. Rust is iron oxide, and is formed by the union of iron and oxygen. *This kind of oxidation is said to be a slow oxidation.* Slow oxidations are constantly taking place in nature and are a part of the process of decay and of breaking down of complex materials into simpler materials.

Heat given off as Result of Oxidation. — One of the most important effects of oxidation lies in the fact that, when anything is oxidized, heat is produced. This heat may be of the greatest use. Coal, when oxidized, gives off heat; this heat boils the water in the tubes of a boiler; steam is generated, wheels of an engine turn, and work is performed. The energy released by the burning of coal may be transformed into any kind of work power. *Energy is the ability to perform work.* We shall later find that the oxidation of certain materials in the bodies of plants or animals releases energy. The heat of the human body is maintained by constant oxidation of food materials within the body.

The Composition of Water. — If an electric current is passed through water[2] by means of the apparatus shown in the Figure, it

[1] The teacher may later introduce experiments in chemistry to demonstrate the physical appearance of such other elements as are used by plants in food making.

[2] A little sulphuric acid must be added to make the liquid a better conductor.

is found that the water separates into two gases, one of which occupies twice as much space as the other in the tubes. If we test the gas present in smaller quantity, we find it to be oxygen. The other gas, colorless, tasteless, and odorless like the oxygen, differs from it by igniting with a slight explosion if a burning match or splinter is introduced in it. As it burns, drops of water are formed, showing that it is passing back to its original condition, that is, it is uniting with oxygen to form water. This gas is *hydrogen*. Hydrogen has a great chemical affinity or liking for other elements, hence it is usually found in nature combined with other elements, as with oxygen to form water.

The Composition of the Soil. — The covering of the earth was probably very different in former ages from what it now is. Its molten plastic mass after cooling formed rock. This rock, by the work of the wind, frost, heat, and water, and plants, has in part been broken into small bits. This is inorganic soil, such as sea sand and gravel. Such soil is formed usually of several elements found in rocks, such as calcium, sodium, magnesium, silicon, potassium, and iron combined with oxygen.

A visit to the woods or to a well-kept garden shows us that there is another kind of soil than the inorganic soil just mentioned. This is the rich, dark soil containing *humus*. Humus is made up in part of dead organic matter, the decayed remains of plants and animals. In such soil we should find relatively more water than in inorganic soil. If we could test the chemical elements to be found in humus, we should find nitrogen, hydrogen, oxygen, and also *carbon*, an important element found in all organic matter.

Carbon. — Carbon is found in many conditions in nature. It makes up a large part of the bodies of plants and animals, and of coal, and it exists in a nearly pure state in the diamond. The presence of carbon can usually be detected by partially burning the substance, carbon showing as a black substance without taste or odor. Carbon may be collected by allowing a candle flame to burn in contact with the underside of a sheet of glass. The black deposit is almost pure carbon.

Oxidation of Carbon and its Result. — If we burn a candle in a closed jar containing air, the flame soon begins to flicker, and then goes out. If the cover of the jar is *carefully* removed, and a

burning match lowered into the jar, the match will at once go out, showing the presence of a gas heavier than air which will not support a flame. We might suspect the presence of nitrogen, but nitrogen would not respond to the test which follows. If we pour into the jar a few spoonfuls of limewater,[1] a colorless liquid, and shake it up with the gas in the jar, the limewater turns milky in color. This is a test for a compound known as *carbon dioxide*. This compound was evidently formed by the union of the carbon with the oxygen of the air in the jar.

All organic or living substances, when oxidized, form carbon dioxide. That oxidation of carbon takes place within our own bodies may easily be proved by exhaling through a clean glass tube into some limewater. The heat of our body (98.5° F.) is the result of oxidation taking place within the body. The heat given off from oxidation of wood or coal in a stove is determined by the supply of oxygen we allow to pass to the burning material. If we open the draft, allowing more oxygen to get to the fire, we increase the heat by more rapid oxidation; if we shut off the oxygen supply, we decrease the amount of oxidation. Does this help to explain our deep breathing after doing hard physical exercise?

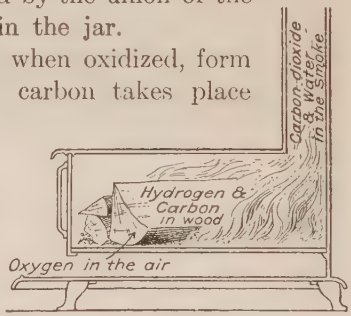

Diagram of combustion or rapid oxidation in a stove.

Problem II. *Are mineral matter and water present in living things?* (*Laboratory Manual, Prob. II.*)

(*a*) *Mineral matter.*

(*b*) *Water.*

Mineral Matter in Living Things. — If a piece of wood is burned in a very hot fire, the carbon in it will all be consumed, and eventually nothing will be left except a grayish ash. This ash is well seen after a wood fire in the fireplace, or after a bonfire of dry leaves. It consists entirely of mineral matter which the plant has taken up from the soil dissolved in water, and which has been stored in the wood or leaves.

[1] Limewater can be made by shaking up a piece of quicklime the size of your fist in about two quarts of water. Filter or strain the limewater into bottles, and it is ready for use.

If we were able by careful analysis to reduce a plant and an animal to the chemical compounds of which they were formed, we should discover that both contained mineral material. We have just seen examples of this in plants. Mineral matter is found in bone, in the shells covering mollusks (clams, snails, etc.), and in other parts of the bodies of animals.

Water in Living Things. — Water forms an important part of the substance of plants and animals. This can easily be proved by weighing a number of green leaves, placing them in a hot oven for a few moments, and then reweighing. The same experiment made with a soft-bodied animal, as the oyster, would show even more water than in leaves. Some jelly-fish are composed of over 90 per cent water. The human body contains about 65 per cent water.

Gases Present. — Some gases are found in a free state in the bodies of plants or animals. Oxygen is of course present wherever oxidation is taking place, as is carbon dioxide. Other gases may be present in minute quantities.

Problem III. *The foods that living organisms need. (Laboratory Manual, Prob. III.)*

Composition of Living Matter. — The living part of a plant or animal is made up of the elements carbon, hydrogen, oxygen, and nitrogen, with a very minute amount of several other elements, which collectively we may call mineral matter. The living part of a plant corresponds closely in chemical composition to the living part of an animal. The sugar found in grains or roots of plants has nearly the same chemical formula as the animal sugar found in the liver of man; the oils of a nut or fruit are of composition closely allied to the fat in the body of an animal. These building materials of a plant or animal may be placed in one of the three following groups of substances: *carbohydrates*, materials containing a certain proportion of carbon, hydrogen, and oxygen; *fats* and *oils*, which contain chiefly hydrogen and carbon with less oxygen; and *nitrogenous* or *proteid* substances, which contain nitrogen in addition to the above-mentioned elements. The above three kinds of organic materials also form a large part of the foods of all animals and plants.

Foods. — *What is a food?* We know that if we eat a certain amount of proper foods at regular times, we shall be able to go on doing a certain amount of work, both manual and mental. We know, too, that day by day, if our general health is good, we may

be adding weight to our body, and that added weight comes as the result of taking food into the body. What is true of a boy or girl is equally true of plants. If food is supplied in proper quantity and proportion, they will live and grow; if the food supply is cut off, or even greatly reduced, they will suffer and may die. From this, the definition which follows is evident. *A food is a substance that forms the material for the growth or repair of the body of a plant or animal or that furnishes energy for it.*

Nutrients. — Organic food substances may be classed into a number of groups, each of which may be detected by means of its chemical composition. Such groups of food substances are known as *nutrients*. Let us now examine the nutrients.[1]

Carbohydrates. — Starch and sugar are common examples of this group of substances. The former we find in our cereals, bread, cake, and most of our vegetables. Several forms of sugar are commonly used as food; for example, cane sugar, beet sugar, and glucose or grape sugar. Glucose, found as the natural sugar of grapes, honey, and fruits, is manufactured commercially by pouring sulphuric acid over starch. It is used as an adulterant for many kinds of foods, especially in sirups, honey, and candy.

Fats and Oils. — Fats and oils form an important part of the composition of plants and animals. Examples of food in the form of fat are butter and cream, the oils in nuts, olives, and other fruits, and fat in animals.

Proteids. — Nitrogenous foods, or proteids, contain the element nitrogen in addition to carbon, hydrogen, and oxygen of the carbohydrates and fats and oils. They include some of the most complex substances known to the chemist, and, as we shall see, have a chemical composition very near to that of living matter. Proteids occur in several different forms. White of egg, lean meat, beans, and peas are examples of substances composed in a large part of proteids.

Inorganic Foods. — Water and various salts, some of which, as lime, may be found in drinking water, form important parts in the diet of plants and animals. Later we shall see that green plants, although they use precisely the same foods as we do, take into their bodies the chemical elements which form foods. From

[1] For a fuller explanation of nutrients, see Chapters VI and XXIV.

these *raw* food materials, organic foods are manufactured in the body of the plant.

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III. THE FUNCTIONS AND COMPOSITION OF LIVING THINGS

Problem IV. *An introduction to the nature and work of living organisms. (Laboratory Manual, Prob. IV.)*

(*a*) *A living plant.*

(*b*) *A living insect.*

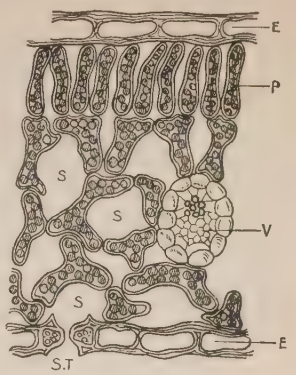
A Living Plant and a Living Animal Compared. — A walk into the fields or any vacant lot on a day in the early fall will give us first-hand acquaintance with many common plants which, because of their ability to grow under sometimes unfavorable conditions, are called *weeds*. Such plants — the dandelion, butter and eggs, the shepherd's purse — are particularly well fitted by nature to produce many of their kind, and by this means drive out other plants which cannot do this so well. On these or other plants we find feeding several kinds of animals, usually insects.

A Weed. Notice the unfavorable habitat. Photograph by W. A. Barbour.

If we attempt to compare, for example, a grasshopper with the plant on which it feeds, we see several points of likeness and difference at once. Both plant and insect are made up of parts, each of which, as the stem of the plant or the leg of the insect, appears to be distinct, but which is a part of the whole living plant or animal. Each part of the living plant or animal which has a separate work to do is called an *organ*. Thus plants and animals are spoken of as living *organisms*.

Functions of the Parts of a Plant. — We are all familiar with the parts of a plant, — the root, stem, leaves, flowers, and fruit.

But we may not know so much about their uses to the plant. Each of these structures differs from every other part, and each has a separate work or function to perform for the plant. *The root holds the plant firmly in the ground and takes in water and mineral matter from the soil; the stem holds the leaves up to the light and acts as a pathway for fluids between the root and leaves; the leaves, under certain conditions, manufacture food for the plant and breathe; the flowers form the fruits; the fruits hold the seeds, which in turn hold young plants which are capable of reproducing adult plants of the same kind.*



Section through the blade of a leaf, as seen under the compound microscope; *S*, air spaces, which communicate with the outside air; *V*, vein in cross section; *ST*, breathing hole; *E*, outer layer of cells; *P*, green cells.

The Functions of an Animal. — If we examine the grasshopper more carefully, we find that it has a head, a jointed body composed of a middle and a hind part, three pairs of jointed legs, and two pairs of wings. Obviously, the wings and legs are used for movement; a careful watching of the hind part of the animal shows us that breathing movements are taking place; a bit of grass placed before it may be eaten, the tiny black jaws biting little pieces out of the grass. If disturbed, the insect hops away, and if we try to get it, it jumps or flies away, evidently seeing us before we can grasp it. Hundreds of little grasshoppers indicate that the grasshopper can reproduce its own kind, but in other respects the animal seems quite unlike the plant. The animal moves, breathes, feeds, and has sensation, while *apparently* the plant does none of these. It will be the purpose of later chapters to prove that the functions of plants and animals are in many respects similar and that both plants and animals breathe, feed, and reproduce.

Organs. — If we look carefully at the organ of a plant called a leaf, we find that the materials of which it is composed do not appear to be everywhere the same. The leaf is much thinner and more delicate in some parts than in others. Holding the flat, ex-

panded blade away from the branch is a little stalk, the petiole, which extends into the blade of the leaf. Here it splits up into a network of tiny veins which evidently form a framework for the flat blade somewhat as the sticks of a kite hold the paper in place. If we examine under the compound microscope a thin section cut across the leaf, we shall find that the veins as well as the other parts are made up of many tiny boxlike units of various sizes and shapes. These smallest units of building material of the plant or animal disclosed by the compound microscope are called *cells*. The organs of a plant or animal are built of these tiny structures.

Tissues. — The cells which form certain parts of the veins, the flat blade, or other portions of the plant, are often found in groups or collections, the cells of which are more or less alike in size and shape. Such a collection of cells is called a *tissue*. Examples of tissues are the cells covering the outside of the human body, the muscle cells, which collectively allow of movement, bony tissues which form the framework to which the muscles are attached, and many others.

Adaptations of Structure to Function. — If I look at my hand as I write, I notice that the fingers of my right hand grasp the pen firmly; that because of the several joints in the fingers, the wrist, and forearm, free movement can be given to the hand when the muscles attached to the bones move it. The hand is capable of a great number of complicated and delicate movements, most of them associated with the work of grasping objects. Because of the peculiar fitness in the structure of the hand for this work, we say that it is adapted to this, its function, that is, grasping objects. Each organ of the plant is fitted or adapted in some way to do certain kinds of work. It is the object of the chapters following to point out how the parts of a plant or animal are adapted to their various functions.

Problem V. *The structure and general properties of living matter.* (*Laboratory Manual, Prob. V.*)

To the Teacher. — Any simple plant or animal tissue can be used to demonstrate the cell. Epidermal cells may be stripped from the body of the frog or obtained by scraping the inside of one's mouth. The thin skin from

an onion shows well, as do thin sections of a young stem, as the bean or pea. I have found one of the best places to study a tissue and the cells of which it is composed in the leaf of a green water plant, *Elodea*. In this plant the cells are large, and not only the outline of the cells, but the movement of the living matter within the cells, may easily be seen, and most of the parts described in the next paragraph can be demonstrated.

Cells. — *A cell may be defined as a tiny mass of living matter, either living alone or forming the building material of a living thing.* The living matter of which all cells are formed is known as *protoplasm* (from two Greek works meaning *first form*). When viewed under a high magnification of a compound microscope, it is a grayish, semi-fluid mass, seemingly almost devoid of any structure. A careful observer will find, however, that the material seems to be made of a ground mass of fluid with innumerable granules of various size and form floating in the fluid portion. All plant and animal cells appear to be alike in the fact that every living cell possesses a structure known as the *nucleus* (pl. *nuclei*), which is found within the body of the cell.

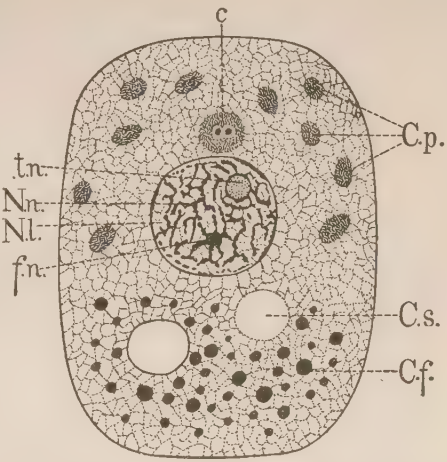


Diagram of a cell (after Wilson). The cell protoplasm contains spaces to hold liquid cell sap (*C.s.*); just above the nucleus (*N.l.*) is a structure called the centrosome (*c*), which aids in cell division; within the nucleus are chromosomes (*N.n.*), which form a network; *t.n.*, nucleolus; *C.p.*, plastids; *C.f.*, lifeless material in the cell.

The nucleus is composed of living matter like the rest of the cell, although it seems to differ in some chemical way from that part of the cell surrounding it. This is seen when a plant or animal is placed in a liquid containing some dye such as logwood. Certain bodies in the nucleus take up the stain much more readily than the rest of the living matter of the cell, taking on a deep black color. They are thus called the *chromosomes* (color-bearing bodies).

The chromosomes, which are believed to be always definite in number for every tissue cell, are of much interest to scientists. It is found that each

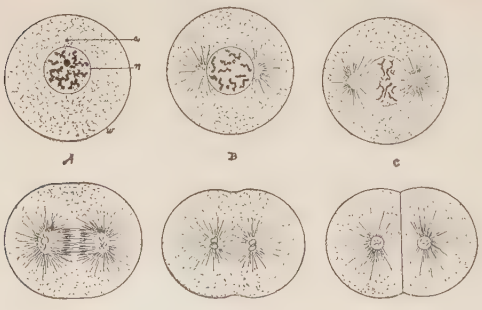
time a cell splits to form two new cells, each chromosome splits lengthwise and the parts go in equal numbers into the nucleus of each of the two new cells thus formed. These chromosomes are supposed to be the bearers of the qualities which we believe can be handed down from plant to plant and from animal to animal; in other words, the inheritable qualities which make the offspring like its parents.

The bulk of the nucleus is filled with a fluid, and in some nuclei a body known as a *nucleolus* is found; it does not, however, seem to be a constant structure. The protoplasm surrounding the nucleus is called *cytoplasm.*

The protoplasm in some cells collects into little bodies called *plastids.* In plant cells the plastids are frequently colored green. This green coloring matter, which is found only in plant cells, is called *chlorophyll,* and green plastids are called *chlorophyll bodies.* The cytoplasm of a cell contain spaces, which are usually filled with a fluid known as *cell sap.* These spaces in the cytoplasm are given the name of *vacuoles.* Frequently nonliving materials are found within the cytoplasm of the cell.

The cell is surrounded by a very delicate living structure called the *cell membrane.* Outside this membrane a wall is formed by the activity of the protoplasm in the cells of plants. These cell walls form wood.

How Cells form Others. — Cells grow to a certain size and then split into two new cells. In this process, which is of very great importance in the growth of both plants and animals, the nucleus divides first. The chromosomes also divide, each splitting lengthwise and the parts going in equal numbers to each of the two cells formed from the old cell. Lastly, the cytoplasm separates, and two new cells are formed. This process is known as *fission.* It is the usual method of growth found in the tissues of plants and animals.



Stages in the division of one cell to form two cells. Note the separation of the chromosomes in the nucleus. Which part of the cell divides first?

Cells of Various Sizes and Shapes. — Plant cells and animal cells are of very diverse shapes and sizes. There are cells so large that they can easily be seen with the unaided eye; for example, the root hairs of plants

and eggs of some animals. On the other hand, cells may be so minute that in the case of the plant cells named bacteria, several million could be placed on the dot of this letter *i*. The forms of cells may be extremely varied in different tissues; they may assume the form of cubes, columns, spheres, flat plates, or may be extremely irregular in shape. One kind of tissue cell, found in man, has a body so small as to be quite invisible to the naked eye, although it has a prolongation several feet in length. Such are some of the cells of the nervous system of man and other large animals, as the ox, elephant, and whale.

Varying Sizes of Living Things. — Plant cells and animal cells may live alone or they may form collections of cells. Some plants are so simple in structure as to be formed of only one kind of cells. Usually living organisms are composed of several groups of different kinds of cells. It is only necessary to call attention to the fact that such collections of cells may form organisms so tiny as to be barely visible to the eye; as, for instance, some water-loving, flowerless plants or many of the tiny animals living in fresh water or salt water, such as the hydra, small worms, and tiny crustaceans. On the other hand, among animals the bulk of the elephant and whale, and among plants the big trees of California, stand out as notable examples.

Relation to Organic and Inorganic Matter. — The inorganic matter covering the earth, as air and water, and forming the great mass of its bulk, is made use of by plants and animals. The latter make their homes in earth, air, or water; they take in the oxygen of the atmosphere; they use the water for drinking; but in the main their food consists of organic matter. Plants, on the other hand, manufacture food out of the dead organic and inorganic matter contained in the soil, air, and water, and then change this food into the living matter of their own bodies. This organic matter in turn may become food for animals.

In the last chapter we found that the classes of substances in an animal or plant and the organic food substances have a similar composition. Let us now consider chemically the substance which forms the basis of all living things.

Chemical Composition of Protoplasm. — Living matter, when analyzed by chemists in the laboratory, seems to have a very complex chemical composition. It is somewhat like a proteid in that it always contains the element nitrogen. It also contains the elements carbon, hydrogen, oxygen, and a little sulphur. Calcium, iron, silicon, sodium, potassium, phosphorus, and other mineral

matters are usually found in very minute quantities in its composition. We believe that the matter out of which plants and animals are formed, although a very complex building material and almost impossible of correct analysis, is composed of the above-named elements. What is of far more importance to us is the fact that it is distinguished by certain *properties* which it possesses and which inorganic matter does not possess.

Properties of Protoplasm. — The properties of protoplasm are as follows: —

(1) It responds to influences or stimulation from without its own substance. Both plants and animals are sensitive to touch or stimulation by light, heat, or electricity. One of the simplest forms of plant life, the slime mold, a mass of naked protoplasm, if placed on a damp blotting paper, moistened at one end with an infusion of leaves, and at the other with a solution of quinine, will crawl to that part of the blotter most like its habitat, that is, moist leaves. Green plants turn toward the source of light. Some animals are attracted to light and others repelled by it; the earthworm is an example of the latter. *Protoplasm is thus said to be irritable.*

(2) *Protoplasm has the power to move and to contract.* Muscular movement is a familiar instance of this power. Plants move their leaves and other organs.

(3) *Protoplasm has the power of absorbing food, of selecting the materials which can be used by it, and to a degree, of selecting materials useful to itself.* A commercial sponge if placed in water will swell up with the water absorbed by it, but this water is not used by the dead skeleton. Protoplasm in the tiny cells projecting from a root (the root hairs) takes in some of the materials which are later used in making food and living matter for the plant. The cells of an animal absorb food materials and seem to be able to select the material. But this selective ability is limited, as both plant and animal cells may be killed by absorbing poisons.

(4) *Protoplasm grows, not as inorganic objects grow, from the outside,*[1] *but by a process of taking in food material and then changing it into living material.* To do this it is evident that the same chem-

[1] *Home Experiment.* — Make a strong solution of alum (two spoonfuls of powdered alum to half a glass of water). Suspend in the solution a thread with a pebble attached to the lower end. Notice where and how crystals of alum grow.

ical elements must enter into the composition of the food substances as are found in living matter. The simplest plants and animals have this wonderful power as certainly developed as the most complex forms of life.

(5) *Protoplasm, be it in the body of a plant or of an animal, uses oxygen.* It breathes. Thus substances taken into the body are oxidized, and release energy for movement and the other activities of plants and animals.

(6) *Protoplasm has the power to rid itself of waste materials,* especially those which might be harmful to it. A tree sheds its leaves, and as a result gets rid of the accumulation of mineral matter in the leaves. Plants and animals alike pass off the carbon dioxide which results from the very processes of living, the oxidation of parts of their own bodies. Animals eliminate wastes containing nitrogen through the skin and the kidneys.

(7) *Protoplasm can reproduce, that is, form other matter like itself.* New plants are constantly appearing to take the places of those that die. The supply of living things upon the earth is not decreasing; reproduction is constantly taking place. In a general way it is possible to say that plants and animals reproduce in a very similar manner. We shall study this more in detail later.

To sum up, we find that living protoplasm has the properties of sensibility, motion, growth, and reproduction alike in its simplest state as a one-celled plant or animal and as it enters into the composition of a highly complex organism such as a tree, a dog, or a man.

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IV. FLOWERS AND THEIR WORK

Problem VI. *The structure and work of the parts of a flower.* (*Laboratory Manual, Prob. VI.*)

Structure of a Simple Flower. — Flowers of different kinds of plants vary greatly in size, shape, and color. In our study of the flower our problem will be primarily to find out the *use* of the flower to the plant which produces it. To solve this problem we must first learn something of the structure and uses of the parts of a very simple flower. Examples of such flowers are the evening primrose and the sedum (live-forever), both of which are plentiful in the fall.

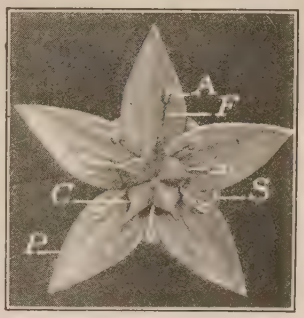
A flower of the sedum, from the side, considerably enlarged; *A*, anther of stamen; *C*, carpel; *F*, filament; *P*, petal; *S*, sepal.

The Floral Envelope. — In such a flower the expanded portion of the flower stalk, which holds the parts of the flower, is called the *receptacle. The five green leaflike parts covering the unopened flower are called the sepals.* Sometimes the sepals are all joined or united in one piece. Taken together, they are called the *calyx.* The sepals come out in a circle or *whorl* on the flower stalk.

The more brightly colored structures are the petals. They form the *corolla.* The corolla is of importance, as we shall see later, in making the flower conspicuous.

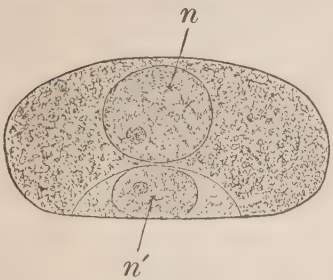
The Essential Organs. — A flower, however, could live without sepals or petals and still do the work for which it exists. *The essential organs* of the flower are within the so-called floral envelope. They consist of the *stamens* and *carpels* (or *pistil*), the

latter being in the center of the flower. The structures with the knobbed ends are called *stamens*. In a single stamen the boxlike part at the end is the *anther;* the stalk is called the *filament*. The anther is in reality a hollow box which produces a large number of little grains called *pollen*. It is necessary for the reproduction of new plants that the pollen get out of the anther. Each carpel or pistil is composed of a rather stout base called the *ovary*, and a more or less lengthened portion rising from the ovary called the *style*. The upper end of the style, which in some cases is somewhat broadened, is called the *stigma*. The stigmatic surface usually secretes a sweet fluid in which grains of pollen from flowers of the same kind can grow.



A flower of the sedum from above; *A*, anther; *C*, carpel; *F*, lament; *P*, petal; *S*, sepal. Notice how the parts come out in circles or whorls.

Pollen. — Pollen grains of various flowers, when seen under the microscope, differ greatly in form and appearance. Some are relatively large, some small, some rough, others smooth, some spherical, and others angular. They all agree, however, in having a thick wall, with a thin membrane under it, the whole inclosing a mass of protoplasm. At an early stage the pollen grain contains but a single cell. When we see it, however, we can distinguish two nuclei in the protoplasm. Hence we know that at least two cells exist there.

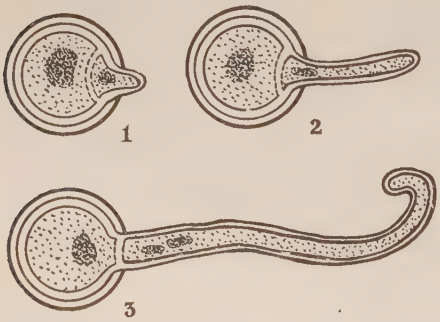


A pollen grain highly magnified. It contains two nuclei (*n*, *n′*) at the stage here represented.

Growth of Pollen Grains. — Under certain conditions a pollen grain will burst open and grow. This growth can be artificially produced in the laboratory by sprinkling pollen from well-opened flowers of sweet pea or nasturtium on a solution of 15 parts of sugar to 100 of water. Left for a few hours in a warm and moist place and then examined under the microscope, the grains of pollen will

be found to have germinated, a long, threadlike mass of protoplasm growing from it into the sugar solution. The presence of this sugar solution was sufficient to induce growth. When the pollen grain germinates, one of the nuclei enters the threadlike growth (this growth is called the pollen tube; see Figure) *The cell which grows into the pollen tube is known as the sperm cell.*

Fertilization of the Flower. — If we cut the pistil of a large flower (as a lily) lengthwise, we notice that the style appears to be composed of rather spongy material in the interior; the ovary is hollow and is seen to contain a number of rounded structures which appear to grow out from the wall of the ovary. These are the *ovules.* The ovules, under certain conditions, become *seeds.* An explanation of these conditions may be had if we examine, under the microscope, a very thin section of a pistil, on which pollen has begun to germinate. The central part of the style is found to be either hollow or composed of a soft tissue through which the pollen tube can easily grow. Upon germination, the pollen tube grows downward through the spongy center of the style, follows the path of least resistance to the space within the ovary, and there enters the ovule. It is believed that some chemical influence thus attracts the pollen tube. When it reaches the ovary, the sperm cell penetrates an ovule by making its way through a little hole called the *micropyle.* It then grows toward a clear bit of protoplasm known as the *embryo sac.* The embryo sac is an ovoid space, microscopic in size, filled with semifluid protoplasm containing several nuclei. (See Figure.) *One of the nuclei, with the protoplasm immediately surrounding it, is called the egg cell.* It is this cell that the sperm cell of the pollen tube grows toward; ultimately the sperm cell reaches the egg cell and unites with it. *The two cells,*



Three stages in the germination of the pollen grains; one of the nuclei in (3) is the sperm cell nucleus. Drawn under the compound microscope.

after coming together, unite to form a single cell. This process is known as fertilization. This single cell formed by the union of the pollen tube cell or sperm and the egg cell is now called a *fertilized egg.*

Development of Ovule into Seed. — *The primary reason for the existence of a flower is that it may produce seeds from which future plants will grow.* The first beginning of the growth of the seed takes place at the moment of fertilization. From that time on there is a growth within the ovule of a little structure called the *embryo. The embryo will give rise to the future plant. After fertilization the ovule grows into a seed.*

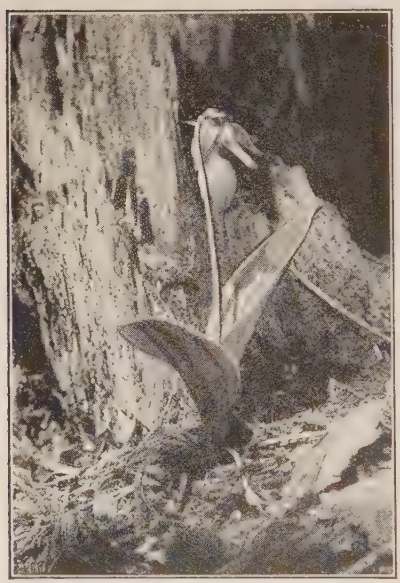
Fertilization of the ovule. A pistil cut down lengthwise (only one side shown). The pollen tube is seen entering the cavity (locule) of the ovary.

Problem VII. *A study of cross-pollination and some means of bringing it about. (Laboratory Manual, Prob. VII.)*

(*a*) *Adaptations in the flower.*
(*b*) *Adaptations in an insect agent.*
(*c*) *Other agents.*

History of the Discoveries regarding Pollination of Flowers. — Although the ancient Greek and Roman naturalists had some vague ideas on the subject of fertilization, it was not until the latter part of the eighteenth century that it was demonstrated that pollen was necessary for the growth of the embryo within a seed. In the latter part of the eighteenth century a book appeared in which a German named Conrad Sprengel worked out the facts that the structure of certain flowers seemed to be adapted to the visits of insects. Certain facilities were offered to an insect in the way of easy foothold, sweet odor, and especially food in the shape of pollen and nectar, the latter

a sweet-tasting substance manufactured by certain parts of the flower known as the nectar glands. Sprengel further discovered the fact that pollen could be and was carried by the insect visitors from the anthers of the flower to its stigma. It was not until the middle of the nineteenth century, however, that an Englishman, Charles Darwin, worked out the true relation of insects to flowers by his investigations upon the cross-pollination of flowers. *By pollination we mean the transfer of pollen from an anther to the stigma of a flower. Self-pollination is the transfer of pollen from the anther to the stigma of the same flower; cross-pollination is the transfer of pollen from the anthers of one flower to the stigma of another flower of the same kind.* Many species of flowers are self-pollinated and do not do so well in seed production if cross-pollinated, but Charles Darwin found that some flowers which were self-pollinated did not produce so many seeds, and that the plants which grew from their seeds were smaller and weaker than plants from seeds produced by cross-pollinated flowers of the same kind. He also found that plants grown from cross-pollinated seeds tended to *vary* more than those grown from self-pollinated seed. This has an important bearing, as we shall see later, in the production of new varieties of plants. Microscopic examination of the stigma at the time of pollination also shows that the pollen from another flower germinates before the pollen which has fallen from the anthers of the same flower. This latter fact alone in most cases renders it unlikely for a flower to produce seeds by its own pollen. Darwin worked for many years on the pollination of many



A wild orchid, a flower of the type from which Charles Darwin worked out his theory of cross-pollination by insects.

insect-visited flowers, and discovered in almost every case that showy, sweet-scented, or otherwise attractive flowers were adapted or fitted to be cross-pollinated by insects. He also found that, in the case of flowers that were inconspicuous in appearance, often a compensation appeared in the odor which rendered them attractive to certain insects. The so-called carrion flowers, pollinated by flies, are examples, the odor in this case being like decayed flesh. Other flowers open at night, are white, and provided with a powerful scent so as to attract night-flying moths and other insects. Flowers adapted to be cross-pollinated by insects are frequently irregular in shape. Thus butter and eggs is a flower which is well fitted for cross-pollination by insects.

Spike of butter and eggs (*linaria*).

Butter and Eggs (*Linaria linaria*). — From July to October this very abundant weed may be found especially along roadsides and in sunny fields. The flower cluster forms a tall and conspicuous flower cluster known as a *spike*, the yellow and orange flowers being arranged so that they come out directly from the main flower stalk.

The corolla projects into a spur on the lower side; an upper two-parted lip shuts down upon a lower three-parted lip. The four stamens are in pairs, two long and two short. (The stamens of two lengths are so placed that they may allow self-pollination in stormy weather, when insects fail to reach the flower. The instructor should explain this.)

Certain parts of the corolla are more brightly colored than the rest of the flower. This color is a guide to insects. Butter and eggs is visited most by bumblebees, which are guided by the orange lip to alight just where they can push their way into the flower. The bee, seeking the nectar secreted in the spur, brushes his head and shoulders against the stamens. Visiting another flower of the cluster, it would be an easy matter accidentally to transfer this pollen to the stigma of another flower. In this way cross-pollination is effected.

Insects as Pollinating Agents.[1] — No one who sees a hive of bees with their wonderful communal life can fail to see that these insects play a great part in the life of the flowers near the hive. A famous observer named Sir John Lubbock tested bees and wasps to see how many trips they made daily from the hive to the flowers, and found that the wasp went out on 116 visits during a working day of 16 hours, while the bee made but a few less visits, and worked only a little less time than the wasp worked. It is evident that in the course of so many trips to the fields a bee must light on and cross-pollinate many hundreds of flowers.

Study of a Bee. — The body of a bee (and of all other insects) is divided into three parts. Attached to the middle part (the

Bumblebees; *a*, queen; *b*, worker; *c*, drone.

thorax) are three pairs of jointed legs and two pairs of tiny wings. By the legs and the jointed body we are able to distinguish insects

[1] **Suggestions for Field Work.** — At this point, at least one field trip should be introduced for the purpose of studying under natural conditions the cross-pollination of flowers by insects. For suggestions for such a trip, see Hunter and Valentine, *Manual*, page 207. Many of the following exercises on fall flowers may profitably be taken in the field and reported on by the pupil as class exercises. Excellent suggestions for a field trip may be found in Andrews, *Botany All the Year Round*. To make such a trip successful, the teacher should first know the locality and should have directions in the hands of each pupil before starting. Flowers which are abundant in the fall and which show adaptations easily worked out by pupils are the evening primrose (*Onagra biennis*), moth mullein (*Verbascum blattaria*), and jewel weed (*Impatiens biflora*).

Directions for work on these forms and for a field trip will be found in the Laboratory Manual, Prob. VII.

from other animals. If we look closely at the bee, we find the body and legs more or less covered with tiny hairs; especially are these hairs found on the legs. *When a plant or animal structure is fitted to do a certain kind of work, we say it is adapted to do that work.* The joints in the leg of the bee fit it for complicated movements; the arrangement of stiff hairs along the edge of a concavity in one of the joints of the leg forms a structure well fitted to hold pollen. In this way pollen is collected by the bee and taken to the hive to be used as food. But while gathering pollen for itself, the dust is caught on the hairs and other projections on the body or legs and is thus carried from flower to flower. Thus cross-pollination may be effected.

Pollination not intended by the Bee. — The cross-pollination of flowers is not planned by the bee; it is simply an incident in the course of the food gathering. The bee visits a large number of flowers of the same species during the course of a single visit from the hive, and it is then that cross-pollination takes place.

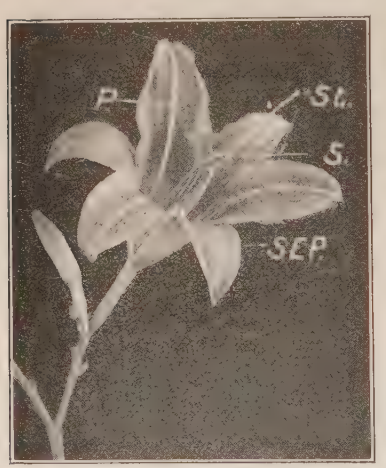
Suggestions for Field Work. — In any locality where flowers are abundant, try to answer the following questions: How many bees visit the locality in ten minutes? How many other insects alight on the flowers? Do bees visit flowers of the same kinds in succession, or fly from one flower on a given plant to another on a plant of a different kind? If the bee lights on a flower cluster, does it visit more than one flower in the same cluster? How does a bee alight? Exactly what does the bee do when it alights?

Is Color or Odor in a Flower an Attraction to an Insect? — Try to decide whether color or odor has the most effect in attracting bees to flowers. Sir John Lubbock tried an experiment which it would pay a number of careful pupils to repeat. He placed a few drops of honey on glass slips and placed them over papers of various colors. In this way he found that the honeybee, for example, could evidently distinguish different colors. Bees seemed to prefer blue to any other color. Flowers of a yellow or flesh color were preferred by flies. It would be of considerable interest for some student to work out this problem with our native bees and with other insects. Test the keenness of sight in insects by placing a white object (a white golf ball will do) in the grass and see how many insects will alight on it. Try to work out some method by which you can decide whether a given insect is attracted to a flower by odor alone.

The Sight of the Bumblebee. — The large eyes located on the sides of the head are made up of a large number of little units, each of which is considered to be a very simple eye. The large eyes are therefore called

the *compound eyes*. All insects are provided with compound eyes, with simple eyes, or, in most cases, with both. The simple eyes of the bee may be found by a careful observer between and above the compound eyes.

One would suppose that with so many eyes the sight of insects would be extremely keen, but such does not seem to be the case. Insects can, as we have already learned, distinguish differences in color at some distance; they can see *moving* objects, but they do not seem to be able to make out form well. To make up for this, they appear to have an extremely well-developed sense of smell. Insects can distinguish at a great distance odors which to the human nose are indistinguishable. Night-flying insects, especially, find the flowers by the odor rather than by color.



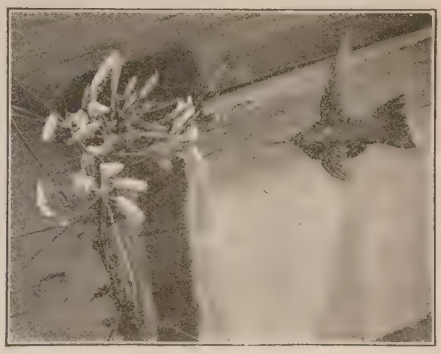
A lily: *P*, petal; *S*, stamen (anther); *SEP*, sepal; *St*, pistil (stigma). Note the nectar guides on the petals.

Nectar and Nectar Glands. — The bee is attracted to a flower for food. This food may consist of pollen or *nectar*. Nectar is a sugary solution that is formed in the flower by little collections of cells called the *nectar glands*. The nectar glands are usually so placed that to get to them the insect must first brush the stamens and pistil of the flower. Frequently the location of the nectaries (nectar glands) is made conspicuous by brightly colored markings on the corolla of the flower. The row of dots seen in the tiger lily is an example.

Head of the bumblebee; *a*, antenna; *g*, tongue used in licking the nectar from flowers; *m*, maxillæ.

Mouth Parts of the Bee. — The mouth of the bee is adapted to take in the foods we have mentioned, and is used for the purposes for which man would use the hands and fingers. The honeybee laps or sucks nectar from flowers, it chews the pollen, and it uses part of the mouth as a trowel in making the honeycomb. A glance at the Figure shows us that the mouth

parts of the bee are complex. The parts consist of a pair of very small jaws or mandibles, certain other structures, *maxillæ*, part of the lower lip called the *labial palps*, and a long tonguelike structure called the *ligula*. The uses of the mouth parts may be made out by watching a bee on a well-opened flower.



A humming bird just about to cross-pollinate a flower.

Other Flower Visitors.[1]— Other insects besides the bee are pollen carriers for flowers. Among the most useful are moths and butterflies. Both insects feed only on nectar, which they suck through a long tube-like *proboscis*. The heads and bodies of these insects are more or less thickly covered with hairs, and the wings are thatched with hairlike, tiny scales. All these structures are of use to the flower because they collect and carry pollen. Projecting from each side of the head of a butterfly is a fluffy structure, the palp. This collects and carries a large amount of pollen, which is deposited upon the stigmas of other flowers when the butterfly pushes its head down into the flower tube after nectar.

The common swallow-tailed butterfly on clover. Bumblebees usually are the agents which cross-pollinate this flower.

Flies and some other insects are agents in cross-pollination. Humming birds are also active agents in some flowers. Snails are said in rare instances to carry pollen. Man and the domesticated animals undoubtedly frequently pollinate flowers by brushing past them through the fields.

[1] If the study of other insects is taken up in the fall in connection with the flower, the student should be referred to parts of Chapters XX and XXI and to the Laboratory Manual.

Cross-pollination of a Head (Clover). — In a flower cluster called a head, a closely massed cluster of little flowers as clover, cross-pollination is usually effected by bumblebees which rapidly work from one flower to another in the same cluster, inserting their tongues deep into the flower cup. The butterfly shown in the illustration inserts its proboscis (seen curled up like a watch spring on the underside of the head) into the flower.

A composite head.

Cross-pollination of a Composite Head. — This flower cluster, so often mistaken for a single flower, is found only in the great Composite family, to which so many of our commonest flowers and weeds belong. The daisy, aster, goldenrod, and sunflower are examples of the Compositæ.

The composite head is well seen in a daisy or the sunflower. This head has an outer circle of green parts. These parts look like sepals, but in reality are a whorl of leaflike parts. Taken together these form an *involucre*. Inside the involucre is a whorl of brightly colored, irregular flowers called the *ray flowers*. They appear to act, in some instances at least, as an attraction to insects by showing a definite color (see the common dogwood, *Cornus florida*). The flowers occupying the center of the cluster are the *disk flowers*. Such a flower examined under the hand lens is found to be perfect. A careful observer will find that the anthers are united in a ring around the pistil. This is a typical condition in the Compositæ. The stamens ripen first and grow up around the stigma, which ripens later. The stigma splits (see *a*), and pollen from another flower brought to its surface will germinate there.

Section through composite head, showing a disk flower (*a*), a ray flower (*c*), and the involucre (*d*).

Other examples. — Many other examples of adaptations to secure cross-pollination by means of the visits of insects might be given. The mountain laurel, which makes our hillsides so beautiful in late spring, shows a remarkable adaptation in having the stamens caught in little pockets of the corolla. The weight of the visiting insect on the corolla releases the anther of the stamen from the pocket in which it rests, and the body of the visitor is dusted with pollen.

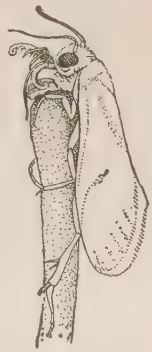
The milkweed or butterfly weed (*Asclepias cornuti*) is another example of a flower adapted to insect pollination.[1]

Milkweed, showing the flower cluster called an umbel.

Still another example of cross-pollination is found in the yucca, a desert-loving semitropical lily (to be seen in most botanic gardens). In this flower the stigmatic surface is above the anther, and the pollen is sticky and could not be transferred except by insect aid. This is accomplished in a remarkable manner. A little moth, called the *pronuba*, gathers pollen from an anther, flies away with this load to another flower, there deposits an egg in the ovary of the pistil, and then rubs its load of pollen over the stigma of the flower. The young hatch out and feed on the young seeds which have been fertilized by the pollen placed on the stigma by the mother. They eat some of the developing seeds and then bore out of the seed pod and escape to the ground, leaving the plant to develop the remaining seeds without further molestation.

Pod of yucca pierced by the pronuba.

The fig insect (*Blastophaga grossorum*) is another member of the insect tribe that is of considerable economic impor-



Pronuba pollinating pistil of yucca.

[1] For an excellent account of cross-pollination of this flower, the reader is referred to W. C. Stevens, *Introduction to Botany*. Orchids are well known to botanists as showing some very wonderful adaptations. For simple reference reading, see Coulter, *Plant Relations*. A classic easily read is Darwin, *On the Fertilization of Orchids*.

tance. It is only in recent years that the fruit growers of California have discovered that the fertilization of the female flowers is brought about by a gallfly which bores into the young fruit.[1] The last two cases are only some of the many examples of mutual help among plants and animals.

Pollination by the Wind. — Not all flowers are dependent upon insects for cross-pollination. Many of the earliest of spring flowers appear almost before the insects do. These flowers, needing no conspicuous colors or showy corolla to attract insects, often lack this part altogether. In fact, we are apt entirely to overlook the flowers which appear in the spring upon our common forest and shade trees. In many trees the flowers appear before the leaves come out. Such flowers are dependent upon the wind to carry pollen from the stamens of one flower to the pistil of another. Most of our common trees, oak, poplar, maple, and others, are cross-pollinated almost entirely by the wind.

The staminate flower of the corn. Notice the hanging anthers full of pollen.

Among the adaptations that a wind-pollinated flower shows are: (1) The development of very many pollen grains to each ovule. In one of the insect-pollinated flowers, that of the night-blooming cereus, the ratio of pollen grains to ovules is about eight to one. In flowers which are to be pollinated by the wind, a large number

[1] The teacher is referred to Yearbook of the Department of Agriculture for 1900 for data on the insect which pollinates the Smyrna fig.

of the pollen grains never reach their destination and are wasted. Therefore in such plants several thousands, perhaps hundreds of thousands, of pollen grains will be developed to every ovule produced. Such are the pines. In May and early June the ground under pine trees is often yellow with pollen, and the air may be filled with the dust for miles from the trees. Such, also, is the case with many of the grasses.

(2) The anthers are usually exposed to the wind when ripe. The common plantain and timothy grass are excellent examples.

(3) The pistil of the flower is peculiarly fitted to retain the pollen by having feathery projections along the sides which increase the stigmatic surface. This can be seen in the grass. In the Indian corn the stigmatic surface is the so-called silk which protrudes beyond the covering of modified leaves which form the husk of the ear of corn. All our grains, wheat, rye, oats, and others, have the typical feathery pistil of the wild grasses from which they descended.

(4) The corolla is often entirely lacking. It would only be in the way in flowers that are dependent upon the wind to carry pollen.

Imperfect Flowers. — Some flowers, the wind-pollinated ones in particular, are imperfect; that is, they lack either stamens or pistils. In such flowers, cross-pollination must of necessity follow.

Imperfect flowers of the squash, the corolla removed. Pistillate flower at the left.

If only the staminate flowers (those which contain only stamens) are developed on one plant, and only the pistillate (those which bear only pistils) on another, we call the plant *diœcious*. A common example is the willow.

Other plants bear staminate and pistillate flowers on the same plant. In this case they are said to be *monœcious*. The oak, hickory, beech, birch, walnut, and chestnut are familiar examples.

The pine tree is another example of monœcious tree; the male or staminate flowers appear in tiny clusters called *catkins*, the female or pistillate flowers coming a little later as tiny cones, which in most species of pines take nearly two years to produce seeds.

Water Pollination. An unusual method of pollination is found in those plants which live almost entirely under the water. In eelgrass the pistillate flowers are attached to long, slender stalks and float on the

surface of the water. The staminate flowers, when ripe, break away from their submerged stems and float to the surface. If these float under a pistillate flower, the protruding ends of the pistils catch and retain some of the pollen from the staminate flower. Thus fertilization follows. After pollination, the stalk of the pistillate flower coils up in a spiral and draws the flower under the surface of the water, so that the seeds may ripen in security.

Summary. — If we now collect our observations upon flowers with a view to making a summary of the different devices flowers

A

B

Flowers of the Lady Washington geranium showing the conditions of dichogamy; *A*, flower with stamens ripe, but with the stigma not ready to receive pollen; *B*, the same flower at a later stage; the stamens have withered, but the stigma is now ready to receive pollen.

have assumed to prevent self-pollination and to secure cross-pollination, we find that they are as follows: —

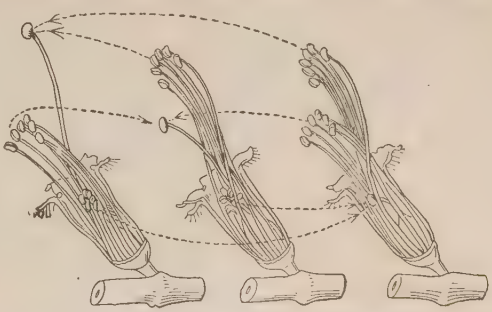
(1) *The stamens and pistils may be found in separate flowers, either on the same or on different plants.*

(2) *The stamens may produce pollen before the pistil is ready to receive it, or vice versa.* This condition is called *dichogamy.*

(3) *The stamens and pistils may be so placed with reference to each other that pollination can be brought about only by outside assistance.*

In some flowers, as is shown by the primula of our hothouses, the stamens and pistils are each of two different lengths in different

flowers. Short styles and long or high-placed filaments are found in one flower, and long styles with short or low-placed filaments in the other. Pollination will be effected only when some of the pollen from a low-placed anther reaches the stigma of a short-styled flower, or when the pollen from a high anther is placed upon a long-styled pistil. Flowers which have this peculiar condition are said to be *dimorphic* (Greek = of two forms). There are, as in the case of the loosestrife, *trimorphic* flowers having pistils and stamens of three lengths.



Condition of stamens and pistils in the spiked loosestrife (*Lythrum salicaria*).

Charles Darwin, who worked out the fertilization of this flower, describes it as follows: "When bees suck the flowers, the anthers of the longest stamens . . . are rubbed against the abdomen and inner sides of the hind legs as is likewise the stigma of the long-styled form (see diagram). The anthers of the midlength stamens and the stigma of the midstyled form are rubbed against the upper side of the thorax and between the front pair of legs. And, lastly, the anther of the shortest stamens and the stigma of the short-styled form are rubbed against the proboscis and the chin; for the bees in sucking the flowers insert only the front part of the head into the flower. . . . It follows that insects will generally carry the pollen of each form from the stamens to the pistil of corresponding length." [1]

Protection of Pollen. — Pollen, in order to be carried effectively by the wind, insects, or other agencies, must be dry. In some flowers the irregular form of the corolla protects the pollen from dampness. Other flowers close up at night, as the morning-glory and four-o'clock. Still others, as the bellflower, droop during a shower or at night.

Pollen is also protected from insect visitors which would carry

[1] *Forms of Flowers*, page 159.

off pollen but give the flower no return by cross-pollinating it. In some flowers access of ants, plant lice, or other small crawling insects to the stamens is rendered difficult by hairs which are developed upon the filaments or on the corolla. Sometimes a ring of sticky material is found making a barrier around the stalk underneath the flower. Many other adaptations of this sort might be mentioned.

Artificial Cross-Pollination and its Practical Benefits to Man. — Artificial cross-pollination is practiced by plant breeders and can easily be tried in the laboratory or at home. First the anthers must be carefully removed from the bud of the flower so as to eliminate all possibility of self-pollination. The flower must then be covered so as to prevent access of pollen from without; when the ovary is sufficiently developed, pollen from another flower, having the characters desired, is placed on the stigma and the flower again covered to prevent any other pollen reaching the flower.

The seeds from this flower when planted *may* give rise to plants with some characters like each of the plants from which the pollen and egg cell came. Artificial fertilization has been made of great practical value to man.

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V. FRUITS AND THEIR USES

Problem VIII. *A study of fruits to discover —*

(a) Their uses to a plant.

(b) The means of scattering.

(c) Their protection from animals and other enemies.

(*Laboratory Manual, Prob. VIII.*)

A Typical Fruit, — the Pea or Bean Pod. — If a withered flower of any one of the pea or bean family is examined carefully, it will be found that the pistil of the flower continues to grow after the rest of the flower withers. If we remove the pistil from such a flower and examine it carefully, we find that it is the ovary that has enlarged. The space within the ovary has become almost filled with a number of almost ovoid bodies, attached along one edge of the inner wall. These we recognize as the young seeds.

Fruit of the black locust; a legume, showing the attachment of the seeds.

The pod of a bean, pea, or locust illustrates well the growth from the flower. The flower stalk, the ovary, and the remains of the style, the stigma, and the calyx, can be found on most unopened pods. If the pod is opened, the seeds will be found fastened to the ovary wall each by a little stalk. That part of the ovary wall which bears the seeds is the *placenta*. The walls of the pod are called *valves*.

The pod, which is in reality a ripened ovary with other parts of the pistil attached to it, is considered as a *fruit*. By definition, *a fruit is a ripened ovary together with any parts of the flower that may be attached to it*. The chief use of the fruit to the flower is to hold and to protect the seeds; it may ultimately distribute them where they can reproduce young plants.

Formation of Seeds. — *Each seed has been formed as a direct result of the fertilization of the egg cell (contained in the embryo sac of the ovule) by a sperm cell of the pollen tube.*

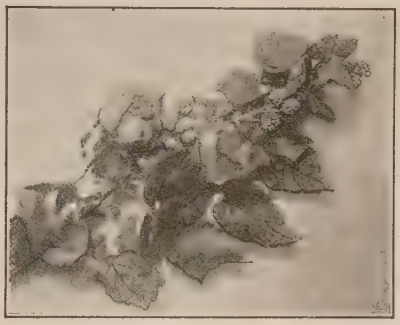
Seed Dispersal.[1] — If you will go out any fall afternoon into the fields, a city park, or even a vacant lot, you can hardly escape seeing how seeds are scattered by the parent plants and trees. Several hundred little seedling trees may often be counted under the shade of a single maple or oak tree. But nearly all these young trees are doomed to die, because of the overshading and crowding. Plants, like animals, are dependent upon their

Young cedars around parent tree. Photographed by Overton.

surroundings for food and air. They need light even more than animals need it, because the soil directly under the shade of the old tree gives only raw food material to the plants, and they must have sunlight in order to make food. This overcrowding is seen in the garden where young beets or lettuce are growing. The gardener assists nature by thinning out the young plants so that they may not be handicapped in their battle for life in the garden by an insufficient supply of air, light, and food.

[1] At this point a field trip may well be taken with a view to finding out how the common fall weeds scatter their seeds. Fruits and seeds obtained upon this trip will make a basis for laboratory work on the adaptations of seed and fruit for dispersal.

It is evidently of considerable advantage to a plant to be able to place its progeny, which are to grow up from seeds, at a considerable distance from itself, in order that the young plant may be provided with a sufficient space to get nourishment and foothold. This is the result which plants have to accomplish. Some accomplish the result more completely than others, and thus are the more successful ones in the battle of life.



The blackberry, a fruit having small seeds scattered by birds.

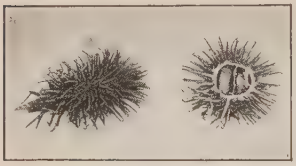
Adaptations for Seed Dispersal; Fleshy Fruits with Hard Seeds. — Plants are fitted to scatter their seeds by having the special means either in the fruit or in the seed. Various agents, as the wind, water, or squirrels, birds, and other animals, make it possible for the seeds to be taken away from the plant.

Fleshy fruits, that is, such fruits as contain considerable water when ripe, are eaten by animals and the seeds passed off undigested. Most wild fleshy fruits have small, hard, indigestible seeds. Birds are responsible for much seed planting of berries or other small fruit. Bears and other berry-feeding animals aid in this as well. Some seeds have especial adaptations in the way of spines or projections. Insects make use of these projections in order to carry them away. Ants plant seeds which they have carried to their nests for a food supply. Nuts are planted by squirrels and blue jays.

Suggestions for Field Work. — Examine the fruit of huckleberry, blackberry, wild strawberry, wild cherry, black haw, wild grape, tomato, currant. Report how many of the above have seeds with hard coatings. Notice that in most, if not in all, edible fruits, the fruit remains green, sour, and inedible until the seeds are ripe. In the state of nature, how might this be of use to a plant?

Hooks and Spines. — Some fruits which are dry and have a hard external covering when ripe possess hooks or spines which enable the whole fruit to be carried away from the parent plant by animals or other moving objects. Cattle are responsible for the spread of

some of our worst weeds in this way. The burdock and clotbur are familiar examples. In both the mass of little hooks is all that remains of an involucre. Thus the whole fruit cluster may be carried about and seeds scattered. In many of the Composites, as in the cockleburs and beggar's-ticks, the fruits are provided with strong curved projections which bear many smaller hooklike barbs.



The cocklebur. Note the curved hooks.

Pappus. — Probably the most important adaptations for dispersal of seeds are those by which the fruit is fitted for dispersal by the wind. That much-loved and much-hated weed, the dandelion, gives us an example of a plant in which the whole fruit is carried by the wind. The parachute, or *pappus*, is an outgrowth of the ovary wall. Many other fruits, notably that of the Canada thistle, are provided with the pappus as a means of getting away. In the milkweed the *seeds* have developed a silky outgrowth which may carry them for miles. In New York city the air is sometimes full of the down from these seeds, which is brought from far over the meadows of New Jersey by the prevailing westerly wind.

Dandelion heads; the middle one a mass of ripe fruits ready to be scattered by the wind. Photographed by Overton.

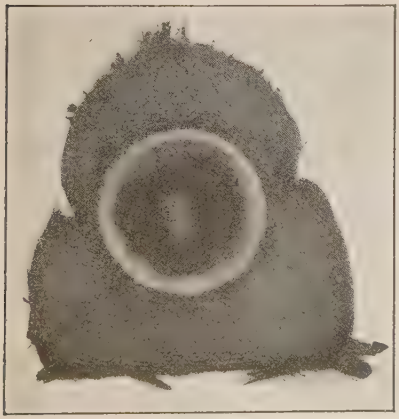
Dehiscent Fruits and how they Scatter Seeds. — One of the many methods of getting rid of seeds is seen in dry fruits. These simply split to allow of the escape of the seeds. Examples of common fruits that split open (*dehiscent*) are seen

in the *follicle* of the milkweed, a fruit which splits along the edge of one valve, the pod or *legume* of a pea and the bean, and the *capsule* of Jimson weed and the evening primrose. In all of the above, the ovary wall does not split open until the seeds are fully ripe. This helps to insure the future growth of the seed. Some dehiscent fruits scatter their seeds through the explosion of the seed case. Such a fruit is the witch-hazel, which explodes with such force that the seeds are thrown several feet. The wild geranium, a five-loculed capsule, splits along the edge of each locule, snaps back, and throws the seed for some distance. Jewelweed fruits burst open in somewhat the same manner.

Capsule of crane's-bill discharging its seed.

Winged Seeds. — The seeds of the pine, held underneath the scales of the cone, are prolonged into wings, which aid in their dispersal. The seeds of many of our trees are thus scattered.

Other Methods. — Sometimes whole plants are carried by the high winds of the fall. This is effected in the plants called tumble-weeds, in which the plant body, as it dries, assumes a somewhat spherical shape. The main stalk breaks off, and the plant may then be blown along the ground, scattering seeds as it goes, until it is ultimately stopped by a fence or bush. A single plant of Russian thistle may thus scatter over two hundred thousand seeds.



Cross section of a coconut in its fibrous husk.

Seeds or fruits (for example, the coconut) may fall into the water and be carried thousands of miles to their new resting place, the fibrous husk providing a boat in which the seed is carried.

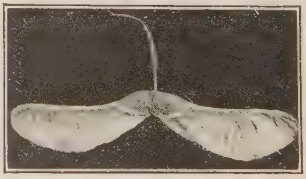
Other seeds may collect in the mud along the banks of ponds or streams. Birds which come there to feed upon these and other material in the mud may carry many seeds in the mud attached to their feet. The great English naturalist, Charles

Darwin, raised eighty-two plants from seeds thus carried by a bird. It is probable that by means of birds and water most of the vegetation has come into existence on the newly formed coral islands of the Pacific Ocean.

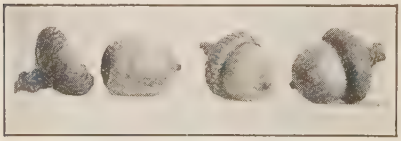
Some Other Forms of Fruits and their Method of Dispersal. — Dry fruits which do not split open to allow of the escape of their seeds are known as *indehiscent* fruits. Some are known as grains. Such are corn, wheat, oats, etc. A grain is simply a one-seeded fruit in which the wall of the ovary has grown so closely to that of the seed that they cannot be separated. Such fruits are usually small and numerous, having a thin outer wall. The seed may easily germinate under favorable conditions. Other indehiscent fruits are nuts, one-seeded fruits with usually hard outer covering, the so-called key fruits of the maples or ash, and many others. Some indehiscent fruits are light and carried by the wind; others are extremely numerous and may be scattered by animals. The key fruits depend upon the wind, while nuts are often carried away, buried, and forgotten by blue jays and squirrels, and thus obtain a new foothold.

Grain; spikes of ripened flowers.

Large Numbers of Seeds. — Plants which do not have especial means for scattering their seeds may make up for this by producing a large number of seeds and holding them in podlike fruits which are easily shaken by the wind. The Jimson weed is a familiar example of such a plant. Each capsule of Jimson weed contains from four hundred to six hundred seeds, depending upon its size. If all of these seeds develop, the whole earth would soon be covered with Jimson weed, to the exclusion of all other forms of plant life. That this is not the case is due to the fact that only those seeds which are advantageously placed can develop; the others will, for various reasons (lack of moisture to start the young seed on its way, poor soil, lack of air or sunlight, overcrowding), fail to germinate.



Key fruit of maple.



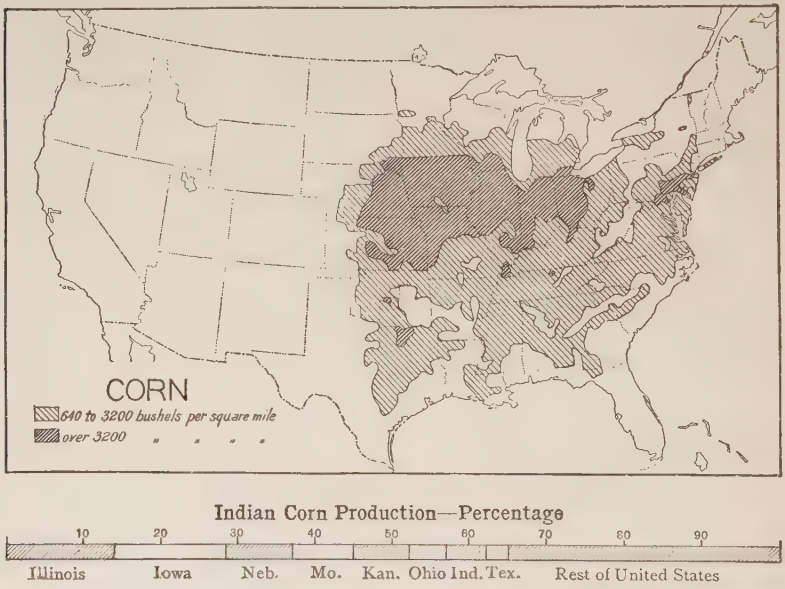
The acorn, a nut in which the involucre partly covers the fruit.

The Struggle for Existence. — Those plants which provide best for their young are usually the most successful in life's race. Plants which combine with the ability to scatter many seeds over a wide territory the additional characteristics of rapid growth, resistance to dangers of extreme cold or heat, attacks of parasitic enemies, inedibility, and peculiar adaptations to cross-pollination or self-pollination, are usually spoken of as weeds. They flourish in the sterile soil of the roadside and in the fertile soil of the garden. By means of rapid growth they kill other plants of slower growth by usurping their territory. Slow-growing plants are thus actually exterminated. Many of our common weeds have been introduced from other countries and have, through their numerous adaptations, driven out other plants which stood in their way. Such is the Russian thistle. First introduced from Russia in 1873, it spread so rapidly that in twenty years it had appeared as a common weed over an area of some twenty-five thousand square miles. It is now one of the greatest pests in our Northwest.

Problem IX. *The economic value of some fruits.* (*Laboratory Manual, Prob. IX.*)

Economic Value of Fruits. — Our grains are the cultivated progeny of wild grasses. Domestication of plants and animals marks epochs in the advance of civilization. The man of the stone age hunted wild beasts for food, and lived like one of them in a cave or wherever he happened to be; he was a nomad, a wanderer, with no fixed home. He may have discovered that wild roots or grains were good to eat; perhaps he stored some away for future use. Then came the idea of growing things at home instead of digging or gathering the wild fruits from the forest and plain. The tribes which first cultivated the soil made a great step in advance, for they had as a result a fixed place for habitation. The cultivation of grains and cereals gave them a store of food which could be used at times when other food was scarce. The word "cereal" (derived from Ceres, the Roman Goddess of Agriculture) shows the importance of this crop to Roman civilization. From earliest times the growing of grain and the progress of civilization have gone hand in hand. As nations have advanced in power, their dependence upon the cereal crops has been greater and greater.

"Indian corn," says John Fiske, in *The Discovery of America*, "has played a most important part in the discovery of the New World. It could be planted without clearing or plowing the soil. There was no need of threshing or winnowing. Sown in tilled land, it yields more than twice as much food per acre as any other kind of grain. This was of incalculable advantage to the English settlers in New England, who would have found it much harder to gain a secure foothold upon the soil if they had had to begin by preparing it for wheat or rye."



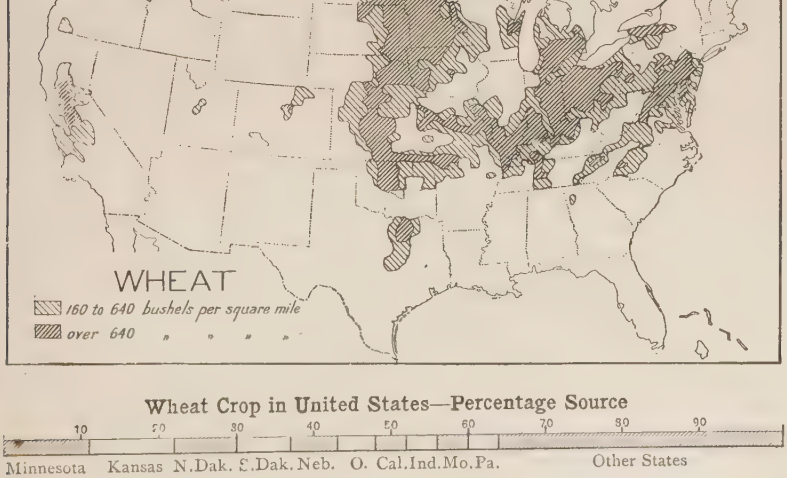
To-day, in spite of the great wealth which comes from our mineral resources, live stock, and manufactured products, the surest index of our country's prosperity is the size of the wheat and corn crop. According to the last census, the amount of capital invested in agriculture was over $20,000,000,000, while that invested in manufacture was less than one half that amount.

Corn. — About three billion bushels of corn were raised in the United States during the year 1910. This figure is so enormous that it has but little meaning to us. In the past half century

our corn crop has increased over 350 per cent. Illinois and Iowa are the greatest corn-producing states, each having a yearly record of over four hundred million bushels. The Figure on page 58 shows the principal corn-producing areas in the United States.

Indian corn is put to many uses. It is a valuable food. It contains a large proportion of starch, from which glucose and alcohol are made. Machine oil and soap are made from it. The leaves and stalk are an excellent fodder; they can be made into paper and packing material. Mattresses can be stuffed with the husks. The pith is used as a protective belt placed below the water line of our huge battleships. Corn cobs are used for fuel, one hundred bushels having the fuel value of a ton of coal.

Wheat. — Wheat is the crop of next greatest importance in size, and is of even greater money value to this country. Nearly seven



Wheat Crop in United States—Percentage Source

hundred millions of bushels were raised in this country in 1910, representing a total money value of over $700,000,000. Seventy-two per cent of all the wheat raised comes from the North Central States and California. About three fourths of the wheat crop is

exported, nearly one half of it to Great Britain. Wheat has its chief use in its manufacture into flour. The germ, or young wheat plant, is sifted out during this process and made into breakfast foods. Flour-making forms the chief industry of Minneapolis, Minnesota, and of several other large and wealthy cities in this country.

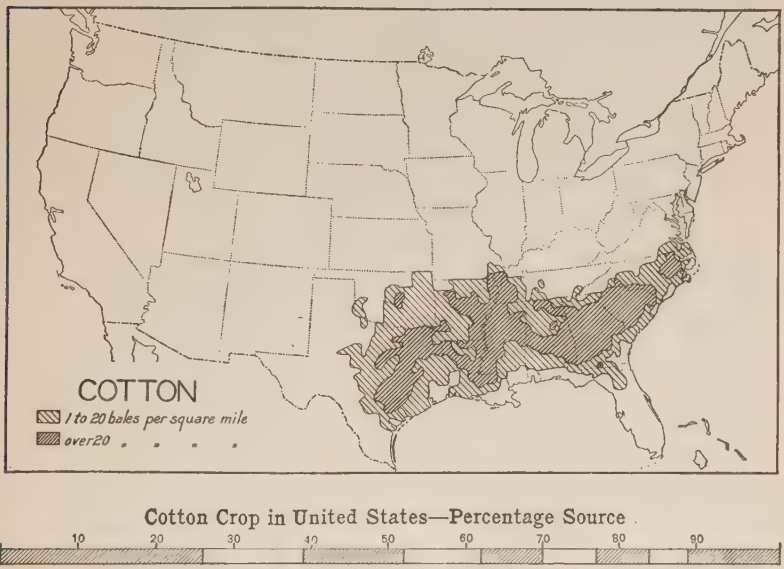
Other Grains. — Of the other grain and cereals raised in this country, oats are the most important crop, over one billion bushels having been produced in 1910. Illinois, Wisconsin, Minnesota, and Iowa produce together over 50 per cent of the total yield. Oats are distinctly a Northern crop, over 95 per cent being grown north of the thirty-sixth parallel. Barley is another largely Northern crop, a staple of some of the northern countries of Europe and Asia. Although such a hardy cereal, almost three fourths of the total production in the United States comes from California, Minnesota, Wisconsin, Iowa; the production of these states may be roughly estimated as 86,000,000 bushels. In this country, it is largely used for making malt in the manufacture of beer.

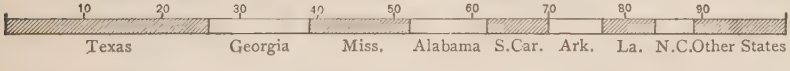
Rye is the most important cereal crop of northern Europe, Russia, Germany, and Austro-Hungary producing over 50 per cent of the world's supply. It makes the principal food for probably one third the people of Europe, being made into "black bread." It is of relatively less importance as a crop now in the United States than in former years.

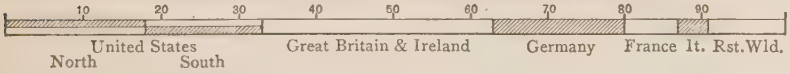
Perhaps one of the most important grain crops for the world (although relatively unimportant in the United States) is rice. A grasslike plant, its fruit, after thrashing, screening, and milling, forms the principal food of one third of the human race. Moreover, its stems furnish straw, its husks make a bran used as food for cattle, and the grain, when distilled, is rich in alcohol.

Nearly related to the grains are our grasses. There is a total forage crop (exclusive of corn stalks) of nearly 100,000,000 tons, valued at over $600,000,000. The best hay in the eastern part of the United States comes from dry timothy grass and clover, the stems and leaves as well as the fruits forming the so-called hay. In some parts of the West a kind of clover called alfalfa is much grown, it being adapted to the semiarid conditions of that part of the country.

Cotton. — Among our fruits cotton is probably that of the most importance to the outside world. Over eleven million bales of five hundred pounds each are raised annually. Of this amount a large amount is exported, the United States producing over three fourths of the world's cotton supply. The relation of source and distribution of the cotton crop can be seen by a glance at the accompanying diagram.







The cotton plant is essentially a warmth-loving plant. Its commercial importance is gained because the seeds of the fruit have long filaments attached to them. Bunches of these filaments, after treatment, are easily twisted into threads from which are manufactured cotton cloth, muslin, calico, and cambric. In addition to the fiber, cottonseed oil, a substitute for olive oil, is made from the seeds, and the refuse remaining makes an excellent cattle fodder.

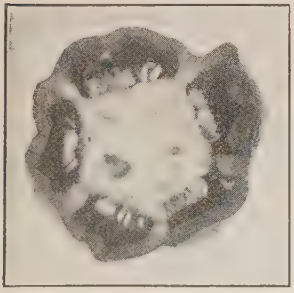
Cotton Boll Weevil. — The cotton crop of the United States has rather recently been threatened with destruction by a beetle called the cotton boll weevil. This insect, which bores into the young pod of the cotton, develops there, stunting the growth of the fruit to such an extent seeds are not produced. The loss in Texas alone is

Map showing spread of the cotton boll weevil. It was introduced from Mexico about 1894. What proportion of the cotton-raising belt was infected in 1908?

estimated at over $10,000,000 a year. The boll weevil, because of the protection offered by the cotton boll, is very difficult to exterminate. The weevils are destroyed by birds, the infected bolls and stalks are burnt, millions are killed each winter by cold, other insects prey on them, but at the present time they are one of the greatest pests the South knows and no sure method of extermination has been found.

Garden Fruits. — Green plants and especially vegetables have come to play an important part in the dietary of man. The diseases known as scurvy and beri-beri, the latter the curse of the far Eastern navies, have been largely prevented by adding vegetables and fruit juices to the dietary of the sailors. People in this country are beginning to find that more vegetables and less meat are better than the meat diet so often used. Market gardening forms the lucrative business of many thousands of people near our great cities. Some of the most important fleshy fruits — squash, cucumbers, pumpkins, and melons — are examples of the *pepo* type of fruit; tomatoes and peppers are types of *berries* in botanical language (for a berry is any soft or juicy fruit containing small seeds). The berries — strawberries, raspberries, and blackberries — of our gardens bring in an annual income of $25,000,000 to our fruit raisers. Beans and peas are important as foods because of their relatively large amount of proteid. Peanuts, rather curiously, are true legumes, like peas and beans, but develop underground. Canning green corn, peas, beans, and tomatoes has become an important business.

Cross section of a cucumber, a pepo. Note the number of locules or spaces in the ovary. How and where are the seeds attached?



Cross section of a green pepper, a berry. How many locules has the ovary? Note the arrangement of the seeds.

Orchard and Other Fruits. — In the United States over one hundred and seventy-five million bushels of apples are grown every year. Pears, plums, apricots, peaches, and nectarines also form large orchards, especially in California. Nuts form one of our important articles of food, largely because of the large amount of proteid contained in them.

The blackberry, a fruit made up of many separate ripe carpels.

The grape crop of the world is commercially valuable, because of the raisins and wine produced. Lemons, oranges, and grapefruit have come in recent years to give a living to many people in this country as well as in other parts of the world. The unfortunate city of Messina was the center of the lemon industry for Italy. Figs, olives, and dates are staple foods in the Mediterranean countries and are sources of wealth to the people there, as are coconuts, bananas, and many other fruits in tropical countries.

Beverages and Condiments. — The coffee and cocoa beans, both products of tropical regions, form the basis of two very important beverages of civilized man. Pepper, black and red, mustard, allspice, nutmegs, cloves, and vanilla are all products manufactured from various fruits or seeds of tropical plants.

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VI. SEEDS AND SEEDLINGS

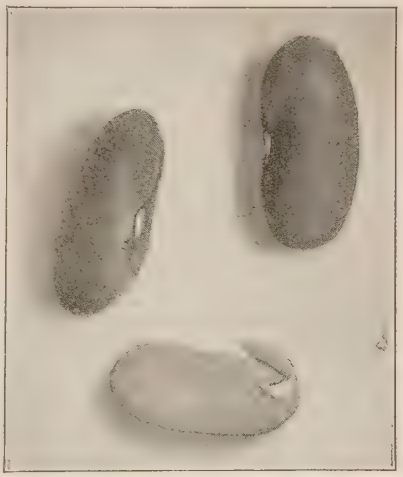
Problem X. *A study of seeds in their relation to the new plant.* (*Laboratory Manual, Prob. X.*)

(*a*) *The relation of the young plant to its food supply.*

(*b*) *How the young plant makes use of its food supply.*

Relation of Flower to Fruit. — We have already found in our study of the fruit that the bean pod is a direct outgrowth from the flower. *It is, in fact, the ovary of the flower, with the parts immediately surrounding it, which has grown larger to make a fruit.*

Use of Fruit. — The fruit holds and protects the *seeds* until the time comes when they are able to germinate and produce new plants like the original plant from which they grew. Then, as we have seen, it helps to scatter them far and wide.

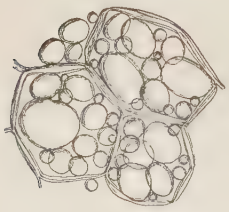


Three views of a kidney bean, the lower one having one cotyledon removed to show the hypocotyl and plumule.

The Bean Seed. — We have already been able to identify in the pod of the bean the style, stigma, and ovary of the flower. The opened pod discloses the seeds lying along one edge of the pod, each attached by a little stalk to the inner wall of the ovary. If we pull a single bean from its attachment, we find that the stalk leaves a scar on the coat of the bean; this scar is called the *hilum*. The tiny hole near the hilum is called the *micropyle*. Turn back to the Figure (p. 37) showing the ovule in the ovary. Find there the little hole through which the pollen tube reached the embryo sac. This hole is called the *micropyle*, and is identical

with the micropyle in the seed. The thick outer coat (the *testa*) is easily removed from a soaked bean, the delicate coat under it easily escaping notice. The seed separates into two parts; these are called the *cotyledons*. If you pull apart the cotyledons very carefully, you find certain other structures between them. The rod-like part is called the *hypocotyl* (meaning *under the cotyledons*). This will later form the root (and part of the stem) of the young bean plant. The first true leaves, very tiny structures, are folded together between the cotyledons. That part of the plant above the cotyledons is known as the *plumule* or *epicotyl* (meaning *above the cotyledons*). All the parts of the seed within the seed coats together form the *embryo* or young plant. A bean seed contains, then, a tiny plant tucked away between the cotyledons and protected by a tough coat.

Food in the Cotyledons. — The problem now before us is to find out how the embryo of the bean is adapted to grow into an adult plant. Up to this stage of its existence it has had the advantage of food and protection from the parent plant. Now it must begin the battle of life alone. We shall find in all our work with plants and animals that the problem of food supply is always the most important problem to be solved by the growing organism. Let us see if the embryo is able to get a start in life (which many animals get in the egg) from food provided for it within its own body.



Starch grains in the cells of a potato tuber.

Test for Starch. — If we shake up a piece of laundry starch in water, in a test tube, and then add to the mixture two or three drops of iodine solution,[1] we find that the particles of starch in the test tube turn purple or deep blue. It has been discovered by experiment that starch, and no *other known substance*, will be turned purple or dark blue. Therefore, iodine solution has come to be used as a test for the presence of starch.

Starch in the Bean. — If we mash up a little piece of a bean cotyle-

[1] Iodine solution is made by simply adding a few crystals of the element iodine to 95 per cent alcohol; or, better, take by weight 1 gram of iodine crystals, $\frac{2}{3}$ gram of iodide of potassium, and dilute to a dark brown color in weak alcohol (35 per cent) or distilled water.

don which has been previously soaked in water, and test for starch with iodine solution, the characteristic blue-black color appears, showing the presence of the starch. If a little of the stained material is mounted in water on a glass slide under the compound microscope, you will find that the starch is contained in the form of little ovoid bodies called *starch grains*. The starch grains and other food products are made use of by the growing plant.

Starches and sugars make up the great class of nutrients known as *carbohydrates*. Of these we shall learn more when we take up the study of foods. (The teacher may here refer to the chapter on Foods.)

Proteid in the Bean. — Another nutrient present in the bean cotyledon is *proteid*. Several tests are used to detect the presence of this nutrient. The following is one of the best known: —

Place in a test tube the substance to be tested; for example, a bit of hard-boiled egg. Pour over it a little strong (80 per cent) nitric acid. Note the color that appears — a lemon yellow. If the egg is washed in water and a little ammonium hydrate added, the color changes to a deep orange, showing that a proteid is present.

If the proteid is in a liquid state, its presence may be proved by heating, for when it coagulates or thickens, as does the white of an egg when boiled, proteid in the form of an *albumin* is present.

Another characteristic proteid test easily made at home is burning the substance. If it burns with the odor of burning feathers or leather, then proteid forms part of its composition.

Proteids occur in several different forms, but the preceding tests will cover most cases commonly met. White of egg, lean meat, beans, and peas are examples of substances composed in a large part of proteid.

A test of the cotyledon of a bean for proteid food with nitric acid and ammonium hydrate shows us that considerable proteid is present. It contains not less than 23 per cent of proteid, 57 per cent of carbohydrates, and about 2 per cent of fats.

The above tests show us that the bean seed contains a large supply of food which, as we shall see, is used by the young plant in its germination.

Beans and Peas as Food for Man. — The young plant within a pea or bean is well supplied with nourishment until it is able to take care of itself. In this respect it is somewhat like a young animal within the egg, a bird or fish, for example. So much food is stored in legumes (as beans and peas are named) that man has come to consider them a very valuable and cheap source of food. The following table shows the amount of food material that can be purchased for 10 cents in fresh and dried peas and beans.

NUTRIENTS FURNISHED FOR TEN CENTS IN BEANS AND PEAS AT CERTAIN PRICES PER POUND

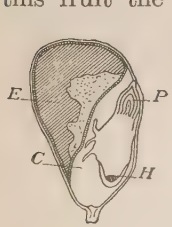
FOOD MATERIALS AS PURCHASED	PRICES PER POUND	TEN CENTS WILL PAY FOR—			
		Total Food Material	Proteid	Fat	Carbohydrates
	Cents	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Kidney beans, dried	5	2.00	0.45	0.04	1.19
Lima beans, fresh, in pod	4	2.50	.08	.01	.25
Lima beans, fresh, shelled	8	1.25	.04	—	.12
Lima beans, canned	6	1.67	.07	.01	.24
Lima beans, dried	6	1.67	.30	.03	1.10
String beans, fresh, 30 cents per peck	3	3.33	.07	.01	.23
Beans, baked, canned	5	2.00	.14	.05	.39
Lentils, dried	10	1.00	.26	.01	.59
Peas, green, in pod, 30 cents per peck	3	3.33	.12	.01	.33
Peas, canned	7	1.43	.05	—	.14
Peas, dried	4	2.50	.62	.03	1.55

The Corn. — The ear of corn is not a single fruit, but a large number of fruits in a cluster like a bunch of bananas, for example. The husk of an ear of corn is simply a covering of leaflike parts which has grown over the young fruits for their better protection. The corn cob is the much thickened flower stalk on which the flowers were clustered. If you have removed the husk carefully, you will see part of each flower remaining attached to each grain of corn. The so-called *silk* of corn is nothing more than a long style and stigma. The corn grain itself was also part of the

flower — the same part that formed the pod of the bean with its contained seeds. The corn grain is a fruit and not a seed.

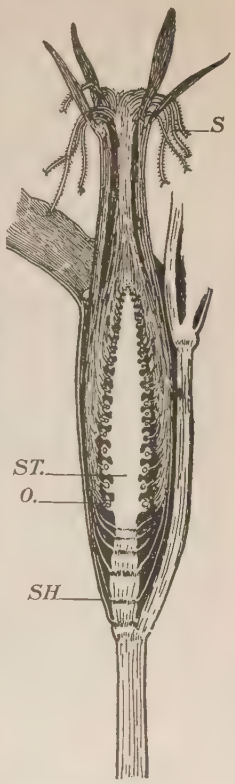
Structure of a Grain of Corn. — Examination of a well-soaked grain of corn discloses a difference in the two flat sides of the grain. A light-colored area found on one surface marks the position of the embryo; the rest of the grain contains the food supply. The scar marking the former attachment of the silk is found near the outer edge of the grain.

A grain cut lengthwise perpendicular to the flat side and then dipped in weak iodine shows two distinct parts, an area containing considerable starch, the *endosperm*, and the embryo or young plant. Careful inspection shows the hypocotyl and plumule (the latter pointing toward the free end of the grain) and a part surrounding them, the *single* cotyledon (see Figure). Here again we have an example of a fitting for future needs, for in this fruit the one seed has at hand all the food material necessary for rapid growth, although the food is here outside the embryo.



A grain of corn, cut lengthwise: *C*, cotyledon; *E*, endosperm; *H*, hypocotyl; *P*, plumule.

Endosperm the Food Supply of Corn. — We do not find that the one cotyledon of the corn grain serves the same purpose to the young plant as did the two cotyledons of the bean. Although we find a little starch in the corn cotyledon, still it is evident from our tests that the endosperm is the chief source of food supply. The study of a thin section of the corn grain under the compound microscope shows us that the starch grains in the outer part of the endosperm are large and regular in size. Those near the edge of the cotyledon are much



Longitudinal section of young ear of corn: *O*, the fruits; *S*, the stigmas; *SH*, sheathlike leaves; *ST*, the flower stalk or peduncle. (After Sargent.)

smaller and quite irregular, having large holes in them. We know that the germinating grain has a much sweeter taste than that which is not growing. This is noticed in sprouting barley or malt. We shall later find that, in order to make use of starchy food, a plant or animal must in some manner change it over to sugar. This change is necessary, because starch cannot be absorbed by the young plant, while sugar can be thus taken in.

A cornfield, showing staminate and pistillate flowers, the latter having become grains of corn.

A Test for Grape Sugar. — Place in a test tube the substance to be tested and heat it in a little water so as to dissolve the sugar. Add to the fluid twice its bulk of Fehling's solution,[1] which has been

[1] To make Fehling's solution (so-called after its discoverer), add to 35 grams of copper sulphate (blue vitriol) 500 c.c. of water. Put aside until it is completely dissolved. Call this solution No. 1.

To 160 grams of caustic soda and 173 grams of Rochelle salt add 500 c.c. of water. Call this solution No. 2.

For use mix equal parts of solution 1 and 2.

The following formula is also convenient: —

I. Copper sulphate: 9 grams in 250 c.c. water.
II. Sodium hydroxide: 30 grams in 250 c.c. water.
III. Rochelle salt: 43 grams in 250 c.c. water.

For use add to equal parts I, II, and III, two parts of water.

previously prepared. Heat the mixture, which should now have a blue color, in the test tube. If grape sugar is present in considerable quantity, the contents of the tube will turn first a greenish, then yellow, and finally a brick-red color. Smaller amounts will show less decided red. No other substance than sugar will give this reaction. If Benedict's test[1] is used, a colored precipitate will appear in the test tube after boiling.

Starch changed to Grape Sugar in the Corn. — That starch is being changed to grape sugar in the germinating corn grain can easily be shown if we cut lengthwise through the embryos of half a dozen grains of corn that have just begun to germinate, place them in a test tube with some Fehling's solution, and heat almost to the boiling point. They will be found to give a reaction showing the presence of sugar along the edge of the cotyledon and between it and the endosperm.

Digestion. — This change of starch to grape sugar in the corn is a process of *digestion*. If you chew a bit of unsweetened cracker

[1] Benedict's Test for Grape Sugar

This test, known from its author as "Benedict's test," will be found described in the 1909 edition of Hawk's *Biochemical Chemistry*. In the latter it is the one labeled "Second Solution."

PREPARATION

Copper sulphate	17.3 grams
Sodium citrate	173. grams
Sodium carbonate (anhydrous)	100. grams
Make up to 1 liter with distilled water	

With the aid of heat dissolve the sodium citrate and carbonate in about 600 c.c. of water. Pour through folded filter paper into a glass graduate and make up to 850 c.c. with distilled water.

Dissolve the copper sulphate in about 100 c.c. of water and make up to 150 c.c. with distilled water.

Pour the carbonate-citrate solution into a large beaker or casserole and add the copper sulphate solution slowly with constant stirring.

The mixed solution is ready for use and *does not deteriorate on standing.*

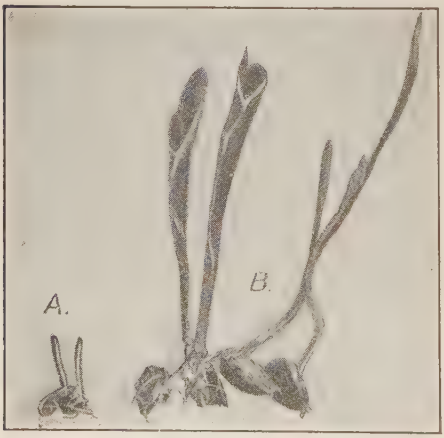
For use add to 5 c.c. of the solution in a test tube 8 drops (more does not disturb the experiment, but 8 drops is sufficient for a good result) of the solution under examination. Boil for one or two minutes and let cool. If grape sugar be present, the entire body of the liquid will be filled with a precipitate which may be red, yellow, or green in color, depending upon the amount of sugar present. Eight drops of 1 per cent dextrose will yield precipitates of large amounts.

The positive reaction is the precipitate, not the *color*. On this account the test may be applied as well in artificial light as in daylight.

in the mouth for a little time, it will begin to taste sweet, and if the chewed cracker, which we know contains starch, is tested with Fehling's solution, some of the starch will be found to have changed to grape sugar. Here again a process of digestion has taken place. In both the corn and in the mouth, the change is brought about by the action of peculiar substances known as digestive ferments, or *enzymes*, and the result is that substances which before digestion would not dissolve in water now will dissolve.

The Action of Diastase on Starch. — The enzyme found in the cotyledon of the corn, which changes starch to grape sugar, is called *diastase*. It may be separated from the cotyledon and used in the form of a powder.

To a little starch in half a cup of water we add a very little (1 gram) of diastase and put the vessel containing the mixture in a warm place, where the temperature will remain nearly constant at about 98° Fahrenheit. On testing part of the contents at the end of half an hour, and the remainder the next morning, for starch and for grape sugar, we find from the latter test that the starch has been almost completely changed to grape sugar. Starch and warm water under similar conditions will not react to the test for grape sugar.



The use of the endosperm to the corn: *A*, seedlings without endosperm; *B*, seedlings with starch in place of endosperm; normal seedlings at the center.

Germinating corn grains, if deprived of their endosperm, soon die. But if the endosperm is removed and a little corn starch paste be stuck to the little plant in place of the endosperm, the development of the embryo will be but little affected (see Figure). Evidently the enzyme formed in the cotyledon has the power to digest the starch paste, and the cotyledon transfers the digested food to the growing parts of the embryo.

Other Foods in Corn Grain. — Other foods besides starch and sugar are present in the corn grain. A test for proteid shows that a considerable amount of this food is present. Oil also is found. In the sweet corn that we eat water forms a very large percentage of its composition by weight.

Monocotyledons, Dicotyledons, and Polycotyledons. — Plants that bear seeds having but a single cotyledon are called *monocotyledons*. (What are some *other* characteristics?) Although we find a good many monocotyledonous plants in this part of the world, this group is characteristic of the tropics, just as the dicotyledons are the type for the temperate climate. Sugar cane and many of the large trees, such as the date palm, palmetto, and banana, are examples. Among the common monocotyledons of the north temperate zone are corn, lily, hothouse smilax, and asparagus. Dicotyledons or plants having two cotyledons in the seed are those with

A hardwood forest showing representative dicotyledonous trees.

A pine seedling. Note the number of cotyledons.

which we come most in contact in daily life. Many of our garden vegetables, peas, beans, squash, melons, etc., all of our great hardwood forest trees, beech, oak, birch, chestnut and hickory, used for the 'trim' of houses, all of our fruit trees, pears, apples, peaches, and plums, and, in fact, a very large proportion of all plants living in the north temperate zone are dicotyledons.

A spruce cone; the seeds are held under the scales of the cone, one of which is shown removed.

A third type of plant, grouped according to the number of cotyledons, is the group called the polycotyledons, represented by the pines and their kin. Such plants furnish most of the lumber and shingles used in the construction of frame houses. The soft woods (as the pines, hemlocks, spruces, and other "evergreens") are also of much value in the manufacture of paper. The wood-pulp industry has grown to such proportions as to be a menace to our softwood forests.

Problem XI. *A study of the factors necessary for awakening (germinating) the embryo within the seed.* (*Laboratory Manual, Prob. XI.*)

(*a*) *Moisture.*
(*b*) *Temperature.*
(*c*) *Oxygen.*
(*d*) *Food.*

External Factors which determine the Growth of Seeds.[1] — We know that a dry seed, after lying dormant and apparently dead for months and sometimes for years, will, when the proper stimuli are applied to it, start in its growth into a new plant. Something from outside the seed must evidently start the growth of the little embryo within the seed coats. There are several factors which

[1] In making a series of experiments it is important to keep the conditions uniform, varying only the one we are testing.

are absolutely necessary for germination. One of these factors is the presence of a certain amount of moisture.

Water a Factor. — We can prove that the bean seed will take up a considerable amount of water and that it swells during the process. Fill a flowerpot or a thin glass bottle almost to the top with dry beans, cover securely as shown in the illustration, and place in water overnight. The force exerted by the swelling seeds is sufficient to break the flowerpot or bottle. It is easy to prove that a dry seed will not germinate. The exact amount of water which is most favorable for the germination of a seed can be determined only by careful experiment. In a very

The expansive force of germinating seeds. The flowerpot to the left was filled with dry beans, a block of wood wired on, and the whole apparatus placed in a pail of water overnight. The result is shown at the right.

Effect of water upon the growth of trees.

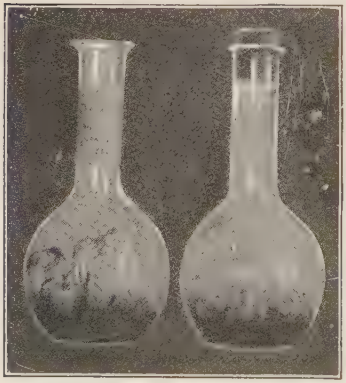
The trees were all planted at the same time in soil that is sandy and uniform. They are irrigated by a small stream running from left to right. Most of the water soaks in before reaching the last trees.

general way it may be said that an oversupply of water will prevent growth of seeds almost as effectually as no water at all. In general the amount most favorable for germination is a moderate supply.

We shall find that although plants may live for a considerable time in water or in sawdust or other materials well moistened in water, yet soil is an essential to the growth of most seed plants. Some plants, as some orchids and "Spanish moss" (a true seed plant), may exist without any connection with soil. Yet most plants need soil water and take from the soil materials needed to make up their living matter.

Moderate Temperature Best. — Another factor influencing the germination of seeds is that of temperature. The temperature at which different seeds germinate varies greatly. Those of you who have a garden at home know that even some varieties of seeds germinate at lower temperatures than others of the same species; for example, early peas, lettuce, or radish seed. As a general rule, increase in temperature is favorable up to a certain point, beyond which it is injurious to the young plant, and seeds exposed to a moderate temperature do better in the long run than those in the heat.

Light has a certain marked effect on young seedlings, which will be considered when we take up the growth of the stem in more detail.



Experiment to show the effect of lack of air on germination.

Some Part of the Air a Factor. — We have already considered the chemical composition of the air in its place as part of the environment of plants and animals. But few of us reason out *why* air is a necessary factor in the growth of plants and animals.

It is an easy matter to prove that peas or beans will not germinate without a supply of air. Equal numbers of soaked peas, placed in two bottles, one tightly stoppered, the other having no stopper, both bottles being exposed to identical conditions of light, temperature, and moisture, show that the seeds in both bottles start

to germinate, but that those in the closed bottle soon stop while those in the open jar continue to grow almost as well as similar seeds placed in an open dish would do.

Why did not the seeds in the covered jar germinate? We have seen that to release the energy contained in a piece of coal we must burn or oxidize it. To do this we must have a constant supply of fresh air containing oxygen. The seed, in order to release the energy locked up in its food supply, must have oxygen, so that the oxidation of the food may take place. *Hence a constant supply of fresh air is an important factor in germination.* It is important that air should penetrate between the grains of soil around a seed. The frequent stirring of the soil enables the air to reach the seed. Air helps break down (oxidizes) some materials in the soil and puts them in a form that the germinating seed can use. This necessity for oxygen shows us at least one reason why the farmer plows and harrows a field and one important use of the earthworm.

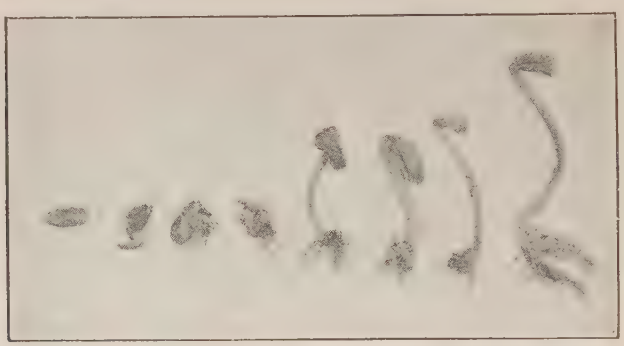
The limewater test; the tube at the right shows the effect of carbon dioxide.

Food oxidized in the Germinating Seed. — But can it be proved that food substances are burned up during the germination of the seeds? To answer this question let us carefully remove the stopper from the stoppered jar and insert a lighted candle. The candle goes out at once. The surer test of limewater shows the presence of carbon dioxide in the jar. The carbon of the foodstuffs of the pea united with the oxygen of the air, forming carbon dioxide. Growth stopped as soon as the oxygen was exhausted. The presence of carbon dioxide in the jar is an indication that a very important process which we associate with animals rather than plants, that of *respiration,* is taking place.

Problem XII. *A study of young plants until they are independent (seedlings). (Laboratory Manual, Prob. XII.)*

Germination. — If you plant a number of soaked kidney beans in damp soil or sawdust and at the end of each day remove a single

seedling, you will be able to obtain a complete record of the growth of the kidney bean. The first signs of germination are the break-



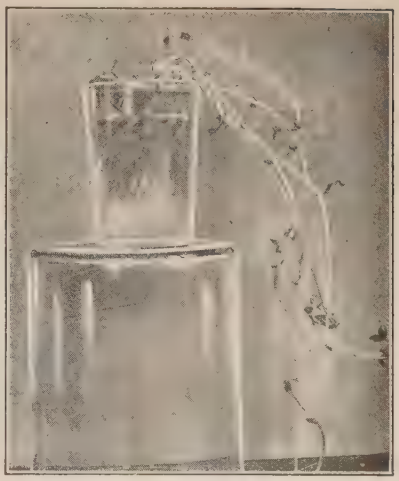
A series of early stages in the germination of a kidney bean.

ing of the testa and the pushing outward of the hypocotyl to form the first root. A little later the hypocotyl begins to curve downward. A later stage shows the hypocotyl lifting the cotyledon upward. In consequence the hypocotyl forms an arch, dragging after it the bulky cotyledons. The stem, as soon as it is released from the ground, straightens out. From between the cotyledons the bud-like plumule or epicotyl grows upward, forming the first true leaves and all of the stem above the cotyledons. As growth continues, we notice that the cotyledons become smaller and smaller, until eventually their food contents having been absorbed into the young plant, they dry up and may fall off. The young plant is now able to care for itself and may be said to have passed through the stages of

Bean seedlings. Note that in the older seedlings at the left the cotyledons have been almost entirely used up.

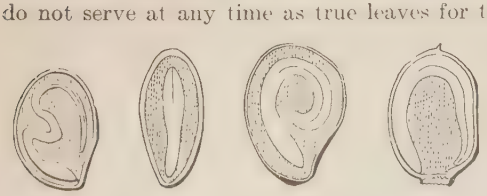
germination. *All the stages passed through by the young plant, from the time the seed begins to sprout until it can take care of itself by means of its roots and leaves, are known as the stages of germination.*

In the pea, growth is likewise at first made largely at the expense of the cotyledons, which never rise above ground. Removal of the cotyledons from half the number of one lot of germinating peas, and exposure to the same conditions as the other half of the same lot, shows that the loss of the cotyledons retards growth and may result in the death of the seedlings.[1]



Experiment to show the function of the cotyledons of the pea, photographed at the end of two weeks. Note the size of the plants at the left, without cotyledons.

Cotyledons as Foliage Leaves. — In the young plants which we have just been studying, the cotyledons hold a reserve food supply, but do not serve at any time as true leaves for the plant. In many dicotyledons, however, the seed leaves do act as true leaves. This may well be seen in the squash seedling. Here the young plant has little or no food stored in the cotyledons; it must be prepared to take care of itself quickly. It does this by means of the rapidly growing cotyledons, which soon unfold as true leaves to the sun.



a *b* *c* *d*

Arrangement of embryo in endosperm (GRAY): *a*, morning-glory; *b*, barberry; *c*, potato; *d*, four-o'clock.

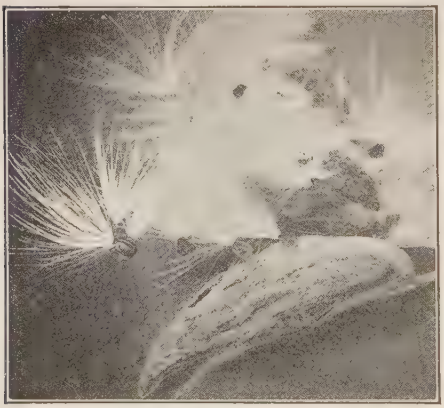
In the seeds of the pea and bean we have found that the embryo takes up all the space within the seed coats. There are some dicotyledonous plants that have food stored outside of the embryo. Such a plant is the castor bean. A section cut vertically through the castor bean discloses

[1] It must be remembered that this is not *quite* a fair test to the pea, because we take away from the young plant part of its own body.

a white oily mass directly under the seed coats. This mass is called the *endosperm*. If it is tested with iodine, it will be found to contain starch; oil is also present in considerable quantity. Within the endosperm lies the embryo, a thin, whitish structure.

The Uses of Seeds. — Not only does a seed serve to continue a species of plant in a certain locality, but it serves to give the plant a foothold in new places. This can be done, as we shall see later, to a limited degree by cuttings, grafting, and in other ways, but the usual way is by the production and planting of seeds. Seeds may be blown by the wind or carried by animals, or by a hundred devices work their way to pastures new, there to establish outposts of their kind.

Immense numbers of seeds may be produced by a single plant. This may be of great economic importance. A single pea plant may produce twenty pods, each containing from six to eight seeds. This would mean the possibility of nearly twenty-five thousand plants produced from the original parent by the end of the second season and the rapid production of a source of food for mankind. A plant of Indian corn may produce over fifteen hundred grains of corn. On the other hand, many weeds produce seed in still greater numbers. A single capsule of Jimson weed has been found to hold over six hundred seeds. A single milkweed may set free over two thousand seeds. The thistle is even more prolific.



Milkweed fruit, showing method of seed dispersal.

Some seeds, especially those of weeds, are able to withstand great extremes of heat and cold and still to retain their ability to germinate. Some have been known to retain their vitality for over fifty years. In plants, the seeds of which show unusual hardiness, it is found that the food supply is often so placed as

to protect the delicate parts of the embryo from injury. The food is in a form not easily dissolved by water or broken up by the action of frost, so that it is kept in a hard state until such a time as it can be softened by the process of digestion during the growth of the plant. It can be seen that plants bearing seeds having some of the above characters have a great advantage over plants bearing seeds that are poorly protected.

Problem XIII. *A study of some methods of plant breeding.* (*Laboratory Manual, Prob. XIII.*)

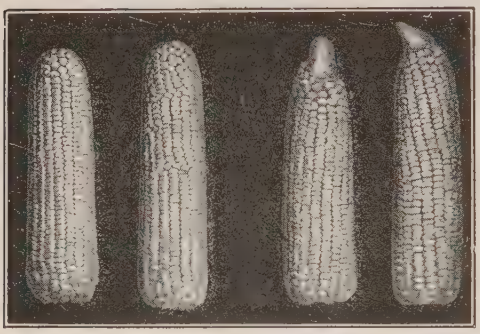
Plant Breeding: Variation of Plants. — Examination of a row of plants in a garden, of a hundred dandelion plants, or careful measurements made on the pupils in a classroom, would show us that no two plants and no two boys or girls have exactly the same measurements or characters. Each plant or animal in a state of nature tends to vary somewhat from its parent. This is a law among plants and animals.

But a second law exists which we also know something about. A plant or animal hands down to its offspring some of the characteristics which it possesses. Each one of us in some way resembles our parents or, it may be, our grandparents. Each plant produced from seed will be in *some* respects like the plant which produced the seed.

These two laws, of *variation* and of *heredity*, the bases on which Charles Darwin explained his theory of evolution, are made use of by plant and animal breeders. Since plants tend to vary and since such variations *may* be continued in their offspring, plant breeders have helped nature by artificially selecting and propagating the plants showing the characters wanted.

Selective Planting. — *By selective planting we mean choosing the best plants and planting the seed from these plants with a view of improving the yield.* In doing this we must not necessarily select the most perfect fruits or grains, but must select seeds from the *best plants*. A wheat plant should be selected not from its yield alone, but from its ability to stand disease and unfavorable conditions. In 1862 a Mr. Fultz, of Pennsylvania, found three heads of beardless or bald wheat while passing through a large field of bearded wheat. He picked them out, sowed them by themselves,

and produced a quantity of wheat now known favorably all over the world as the Fultz wheat. By careful seed selection, some Western farmers have increased their wheat production by 25 per cent. This, if kept up all over the United States, would mean over $100,000,000 a year in the pockets of the farmers.



a *b*

Improvement of corn by selection: *a*, improved type; *b*, original type from which it was developed.

Boys and girls who have gardens of their own can easily try experiments in selection with almost any garden vegetable. Corn is one of the best plants to experiment with. Gather for planting only the fullest ears and those with the largest kernels. You must also select from the plants those that produce the most ears. Plant such corn grains, carefully selected, in a plot by themselves in the garden, and compare their yield with that of the nonselected corn. The accompanying picture shows what can be done by selection. Plants thus produced may become in time varieties of the original species from which they came.

Hybridizing. — We have already seen that pollen from one flower may be carried to another of the same species, thus producing seeds. If pollen from one plant be placed on the pistil of another of an *allied* species or variety, fertilization may take place and new plants be eventually produced from the seeds. Such plants are called *hybrids*.

Hybrids are extremely variable and often are apparently quite unlike either parent plant. Such are some of the results of Luther Burbank's work with the hybrid plums, the Department of Agriculture experiments in the crossing of oranges and lemons and the formation of thousands of new varieties of garden plants of various kinds — beans, peas, tomatoes, and the like.

By far the greatest possibilities to the farmer or fruit grower

seem to come from hybridizing. Of recent years new theories have been advanced accounting for the variation and heredity of plants and animals. One, by a Dutchman named Hugo de Vries, is that new species of plants and animals arise suddenly by "mutations" or steps. This means that new species instead of arising from very slight variations, continuing during long periods of years (as Darwin believed), might arise very suddenly as a very great variation which would at once breed true. It is easily seen that such a condition would be of immense value to breeders, as new plants or animals quite unlike their parents might thus be formed and perpetuated. It will be the future problem of plant breeders to isolate and breed "mutants," as such plants are called.[1]

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[1] The part played by Mendel's law is too difficult to explain to high-school pupils. For a well-organized statement of recent work, see Bailey's *Plant Breeding* or "The Relation of Certain Biological Principles to Plant Breeding," E. M. East, Bulletin 158, Conn. Agri. Exp. Station, New Haven, Conn.

VII. ROOTS AND THEIR WORK

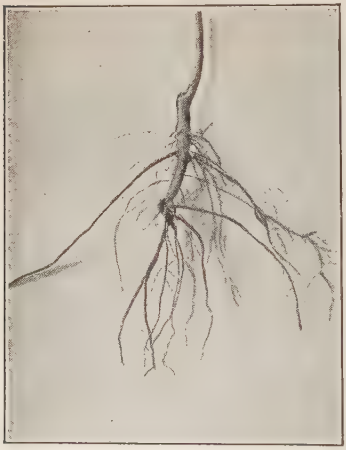
Problem XIV. *A study of roots.* (*Laboratory Manual, Prob. XIV.*)

(*a*) *Factors influencing direction of growth.*

(*b*) *Structure.*

(*c*) *How they absorb soil water.*

The development of a bean seedling has shown us that the root invariably grows first. *One of the most important functions of the root to a young seed plant is that of a holdfast, an anchor to fasten it in the place where it is to develop.* In this chapter we shall find many other uses of the root to the plant, the taking in of water and the mineral and organic matter dissolved therein, the storage of food, climbing, etc. All other functions than the first one stated arise after the young plant has begun to develop.

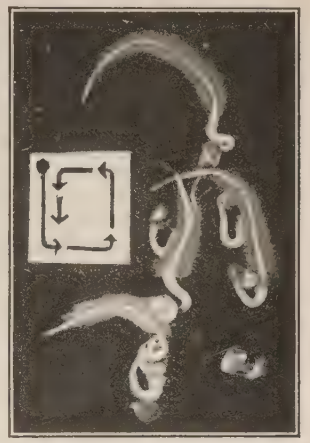


A root system, showing primary and secondary roots.

Root System. — If you dig up a young bean seedling and carefully wash off the roots, you will see that a long root is developed as a continuation of the hypocotyl. This root is called the *primary* root. Other smaller roots which grow from the primary root are called *secondary*, or *tertiary*, depending on their relation to the first root developed.

Downward Growth of Root. Influence of Gravity. — Most of the roots examined take a more or less downward direction. We are all familiar with the fact that the force we call gravity influences life upon this earth to a great degree. Does gravity act on the growing root? This question may be answered by a simple experiment.

Plant mustard or radish seeds in a pocket garden, place it on one edge and allow the seeds to germinate until the root has grown to a length of about half an inch. Then turn it at right angles to the first position and allow it to remain for one day undisturbed. The roots now will be found to have turned in response to the change in position, that part of the root near the growing point being the most sensitive to the change. This experiment seems to indicate that the roots are influenced to grow downward by the force we call gravity.[1]



Revolve this Figure in the direction of the arrows to see if the roots of the radish respond to gravity.

The reaction of the plant (or any living thing) to this force is called geotropism. Roots are stimulated by gravity to grow downward; hence they are said to be positively geotropic.

Experiments to determine Influence of Moisture on a Growing Root. — The objection might well be interposed that possibly the roots in the pocket garden grew downward after water. That moisture has an influence on the growing root is easily proved.

Plant bird seed and the seed of mustard or radish in the underside of a sponge, which should be kept wet, and may be suspended by a string under a bell jar in the schoolroom window. Note whether the roots leave the sponge to grow downward, or if the moisture in the sponge is sufficient to counterbalance the force of gravity.

[1] *The Pocket Garden.* — A very convenient form of pocket germinator may be made in a few minutes in the following manner: Obtain two cleaned four by five negatives (window glass will do); place one flat on the table and place on the glass half a dozen pieces of colored blotting paper cut to a size a little less than the glass. Now cut four thin strips of wood so as to fit on the glass just outside of the paper. Next moisten the blotter, place on it some well-soaked radish or mustard seeds or grains of barley, and cover it with the other glass. The whole box thus made should be bound together with bicycle tape. Seeds will germinate in this box, and with care may live for two weeks or more.

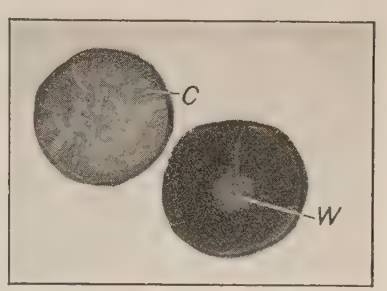
Another experiment is the following: Divide the interior of a shallow wooden box into two parts by an incomplete partition. Partly fill the box with sawdust and place the opening in the partition so that it is below the surface of the sawdust. Plant peas and beans in the sawdust on one side of the partition, water very slightly, but keep the other side of the box well soaked. After two weeks, take up some of the seedlings and note the effect on the roots.

Water a Factor which determines the Course taken by Roots. — *Water, as well as the force of gravity, has much to do with the direction taken by roots.* Water is always found below the surface of the ground, but sometimes at a great depth. In order to obtain a supply of water, the roots of plants frequently spread out for very great distances. Most trees, and all grasses, have a greater area of surface exposed by the roots than by the branches. The mesquite bush, a low-growing tree of the American and Mexican deserts, often sends roots downwards for a distance of forty feet after water. The roots of alfalfa, a cloverlike plant used for hay in the Western states, often penetrate the soil after water for a distance of ten to twenty feet below the surface of the ground.

Dandelion plant. Note the length of the root. Photographed by Overton.

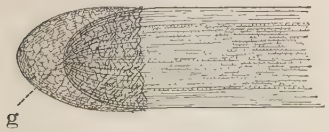
Structure of a Taproot. — To understand fully the structure of the root, it will be necessary for us to examine some large, fleshy root (a taproot), so that we may get a little first-hand evidence as to its internal structure. If you cut open a parsnip or carrot so as to make a cross section of the root, you find two distinct areas — an outer portion, the *cortex*, and an inner part, the *wood*. If you cut another parsnip in lengthwise section, these structures show still

more plainly. An additional fact is seen; namely, that all the smaller roots leaving the main or primary root have a core of wood which bores its way out through the cortex wherever the small rootlets are given off.



A cross section through a taproot (a parsnip): *C*, cortex; *W*, wood. Notice in the right-hand specimen, which has been dipped in iodine, that the core of wood continues out into the rootlets which leave the main root. Where is most starchy food stored in a parsnip?

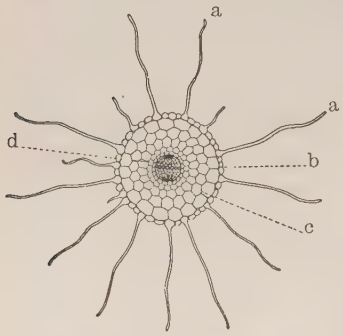
Fine Structure of a Root. — If we could now examine a much smaller and more delicate root in thin longitudinal section under the compound microscope, we should find the entire root to be made up of cells, the walls of which are uniformly rather thin. (Cross sections and longitudinal sections of tradescantia roots are excellent for demonstration of these structures.) Over the lower end of the root is found a collection of cells, most of which are dead, loosely arranged so as to form a cap over the growing tip. This is evidently an adaptation which protects the young and actively growing cells just under the root cap. In the body of the root the central cylinder can easily be distinguished from the surrounding cortex. The cells of the former have somewhat thicker walls.



The end of a growing root, tipped and protected by the root cap; *g*, the growing point. (Considerably magnified.)

In a longitudinal section a series of tubelike structures may be found within the central cylinder. These structures are cells which have grown together at the small end, the long axis of the cells running the length of the main root. In their development the cells mentioned have grown together in such a manner as to lose their small ends, and now form continuous hollow tubes with rather strong walls. Other cells have come to develop greatly thickened walls; these cells give mechanical support to the tubelike cells. Collections of such tubes and supporting woody cells together make up what is known as *fibrovascular bundles*.

Root Hairs. — Careful examination of the root of one of the seedlings of mustard, radish, or barley grown in the pocket germinator shows a covering of tiny fuzzy structures. These structures are very minute, at most 3 to 4 mm. in length. They vary in length according to their position on the root, the most and the longest root hairs being found **near the** point marked *R. H.* in the Figure. These structures are outgrowths of the outer layer of the root (the epidermis), and are of very great importance to the living plant.



Cross section of a young taproot: *a*, *a*, root hairs; *b*, epidermis; *c*, cortex; *d*, fibrovascular cylinder or wood.

Structure of a Root Hair. — A single root hair examined under a compound microscope will be found to be a long, round structure, almost colorless in appearance. The wall, which is very flexible and thin, is made up of cellulose, a substance somewhat like wood in chemical composition, through which fluids may easily pass.

If we had a very high power of the microscope focused upon this cellulose wall, we should be able to find under it another structure, far more delicate than the cell wall. This is called the *cell membrane*. Clinging close to the cell membrane is the protoplasm of the cell. The interior of the root hair is more or less filled with a fluid called *cell sap*. Forming a part of the living protoplasm of the root hair, sometimes in the hairlike prolongation and sometimes in that part of the cell which forms the epidermis, is found a nucleus. The protoplasm, nucleus, and cell membrane are alive; all the rest of the root hair is dead

Young embryo of corn, showing root hairs (*R. H*) and growing stem (*P.*).

material, formed by the activity of the living substance of the cell. *The root hair is a living plant cell* with a wall so delicate that water and mineral substances from the soil can pass through it into the interior of the root.

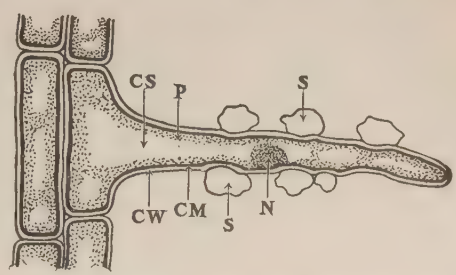
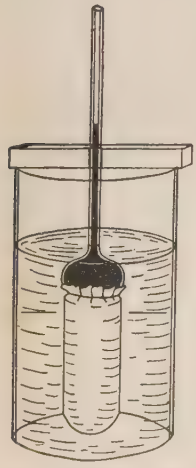


Diagram of a root hair: *CM*, cell membrane; *CS*, cell sap; *CW*, cell wall; *P*, protoplasm; *N*, nucleus; *S*, soil particles.

How the Root absorbs Water. — The process by which the root hair takes up soil water can better be understood if we make an artificial root hair large enough to be easily seen. An egg with part of the outer shell removed so as to expose the soft membrane underneath is an example. Better, a root hair may be *made* in the following way: Pour some soft celloidin into a tube vial; carefully revolve the vial so that an even film of celloidin dries on the inside of the vial. This is removed, filled with white of egg, and tied over the end of a rubber cork in which a glass tube has previously been inserted. When placed in water, it gives a very accurate picture of the root hair at work. After a short time water begins to rise in the tube, having passed through the film of celloidin. If grape sugar, salt, or some other substance which will dissolve in water were placed in the water outside the artificial root hair, it could soon be proved by test to pass through the wall and into the liquid inside.

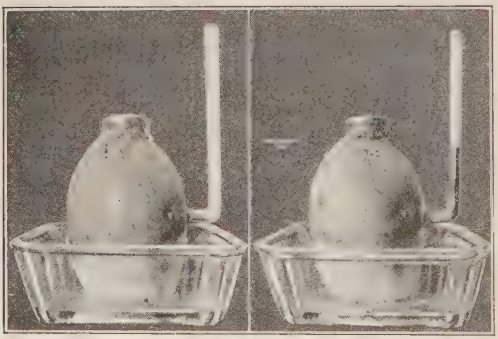


An artificial root hair, showing osmosis taking place.

Osmosis. — To explain this process we must remember that gases and liquids of different densities, when separated by a membrane (a delicate porous lining having no holes visible to the highest power microscope we possess), tend to flow toward each other and mingle, the greatest flow always being in the direction of the denser medium. *The process by which two gases or fluids, separated by a membrane, pass through the mem-*

brane and mingle with each other is called osmosis.[1] The method by which the root hairs take up soil water is exactly the same process. It is by osmosis. The white of the egg is the best possible substitute for living matter; it has, indeed, almost the same chemical formula as protoplasm. The celloidin membrane separating the egg from the water is much like the delicate membrane and wall which separates the protoplasm of the root hair from the water in the soil surrounding it. The fluid in the root hair is denser than the soil water; hence the greater flow is toward the interior of the root hair.

Passage of Soil Water within the Root. — We have already seen that in an exchange of fluids by osmosis the greater flow is always toward the denser fluid. Thus it is that the root hairs take in more fluid than they give up. The cell sap, which partly fills the interior of the root hair, is a fluid of greater density than the water outside in the soil. When the root hairs become filled with water, the density of the cell sap is lessened, and the cells of the epidermis are thus in a position to pass along their supply of water to the cells next to them and nearer to the center of the root. These cells, in turn, become less dense than their inside neighbors, and so the transfer of water goes on until the water at last reaches the central cylinder. Here it is passed over to the tubes of the woody bundles and started



A potato osmometer. The lower end of the potato was cut off and the remainder peeled for about one third of its length. A hole was bored to within three fourths of an inch of the cut end; a small hole was bored at the side of the potato. In the latter was inserted a small L-shaped tube, the lower end being vaselined to make it air-tight. Sugar was then placed in the hole at the top and a cork inserted; water was poured into the dish below. Within two hours the water had risen in the tube, as shown in the right-hand Figure.

[1] For an excellent elementary discussion of osmosis see Moore, *Physiology of Man and other Animals*. Henry Holt and Company.

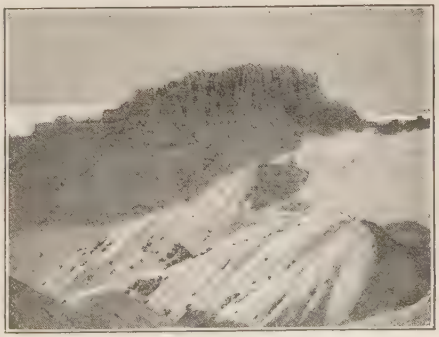
up the stem. The pressure created by this process of osmosis is sufficient to send water up the stem to a distance, in some plants, of twenty-five to thirty feet. Cases are on record of water having been raised in the birch a distance of eighty-five feet.

Physiological Importance of Osmosis. — It is not an exaggeration to say that osmosis is a process not only of great importance to a plant, but to an animal as well. Foods are digested in the food tube of an animal; that is, they are changed into a soluble form so that they may pass through the walls of the food tube and become part of the blood. Without the process of osmosis we should be unable to use much of the food we eat.

Problem XV. *A study of some of the relations between roots and the soil.* (*Laboratory Manual, Prob. XV.*)

(*a*) *Origin of soil.*
(*b*) *Kinds of soil.*
(*c*) *Water-retaining ability.*
(*d*) *Fertility of soils.*
(*e*) *Root hairs and soil.*
(*f*) *Root tubercles and crop rotation.*

Composition of Soil. — If we examine a mass of ordinary loam carefully, we find that it is composed of numerous particles of varying size and weight. Between these particles, if the soil is not caked and hard packed, we can find tiny spaces. In well-tilled soil these spaces are constantly being formed and enlarged. They allow air and water to penetrate the soil. If we examine soil under the microscope, we find considerable water clinging to the soil particles and forming a delicate film around each particle. In this manner most of the water is held in the soil.



Inorganic soil is being formed by weathering.

How Water is held in Soil. — To understand what comes in with the soil water, it will be necessary to find out a little more about soil. Scientists who have made the subject of the composition of the earth a study, tell us that once upon a time at least a part of the earth was molten.

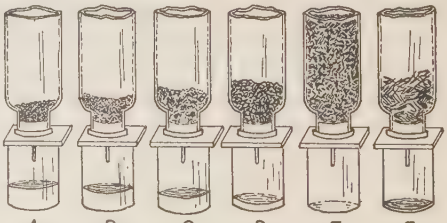
Later, it cooled into solid rock. Soil making began when the ice and frost, working with the heat, chipped off pieces of rock. These pieces in time became ground into fragments by action of ice, glaciers, running water, or the atmosphere. This process is called weathering. Weathering is largely a process of oxidation. A glance at almost any crumbling stones will convince you of this, because of the yellow oxide of iron (rust) disclosed. So by slow degrees this earth became covered with a coating of what we call inorganic soil. Later, generation after generation of tiny plants and animals which lived in the soil died, and their remains formed the first organic materials of the soil.

This picture shows how the forests help to cover the inorganic soil with an organic coating.

You are all familiar with the difference between the so-called rich soil and poor soil. The dark soil simply contains more dead plant and animal life, which forms the portion called *humus*.

Humus contains Organic Matter. — It is an easy matter to prove that black soil contains organic matter, for if an equal weight of carefully dried humus and soil from a sandy road is heated red-hot for some time and then reweighed, the humus will be found to have lost considerably in weight, and the sandy soil to have lost very little. The material left after heating is inorganic material, the organic matter having been burned out.

Organic soil holds water much more readily than inorganic soil, as a glance at the accompanying Figure



Experiment to illustrate the kind of soil which best retains water: *A*, gravel; *B*, sand; *C*, barren soil; *D*, rich soil; *E*, leaf mold; *F*, dry leaves.

shows. If we fill each of the vessels with a given weight (say 100 grams each) of gravel, sand, barren soil, rich loam, leaf mold, and 25 grams of dry, pulverized leaves, then pour equal amounts of water (100 c.c.) on each and measure all that runs through, the water that has been retained will represent the water supply that plants could draw on from such soil.

The Root Hairs take more than Water out of the Soil. — If a root containing a fringe of root hairs is washed off carefully, it will be found to have little particles of soil still clinging to it. Examined under the microscope, these particles of soil seem to be cemented to the sticky surface of the root hair. The soil contains, besides a number of chemical compounds of various mineral substances, — lime, potash, iron, silica, and many others, — a considerable amount of organic material. Acids of various kinds are present in the soil — nitric acid, which comes from the dead bodies of plants and animals as they decay and oxidize; carbonic acid, formed by the union of the carbon dioxide from the roots and the water in the soil, and other acids. These acids so act upon certain of the mineral substances that they become dissolved in the water which is absorbed by the root hairs.

The proportion of each of these mineral materials is very small compared with the water in which they are found. A very great amount of water must be taken up by the roots in order that the plant may get the needed amount of mineral matter with which to build its protoplasm.

Plants will not grow well without certain of these mineral substances. This can be proved by the growth of seedlings in a so-called nutrient solution. Such a solution contains all the mineral matter that a plant uses for food.[1] If certain ingredients of this solution are left out the plants placed in such a solution will not live.

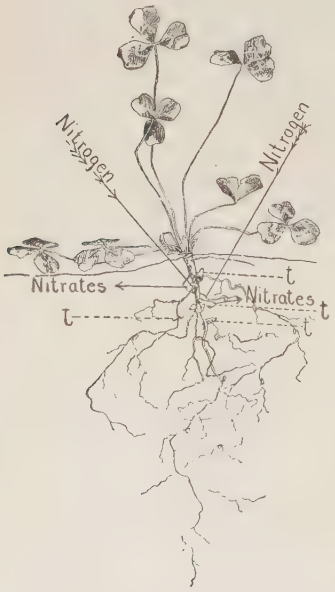
[1] A nutrient solution may be prepared as follows: —

Distilled water (H_2O)	1000.00 c.c.
Potassium nitrate (KNO_3)	1.00 gram
Sodium chloride ($NaCl$)	0.50 gram
Calcium sulphate ($CaSO_4$)	0.50 gram
Magnesium sulphate ($MgSO_4$)	0.50 gram
Calcium phosphate ($Ca_3[PO_4]_2$)	0.50 gram
Ferric chloride ($FeCl_3$)	0.005 gram

(Do not put the ferric chloride into the solution in the first place, but add a drop of it to each bottle when the seedlings are put in.)

Nitrogen in a Usable Form necessary for Growth of Plants. — We learned that humus is made up of decayed plant and animal bodies. A chemical element needed by the plant to make protoplasm is *nitrogen*. This element cannot be taken from either soil water or air in a pure state, but is usually obtained from the organic matter in the soil, where it exists with other substances in the form of *nitrates*. Ammonia and other organic compounds which contain nitrogen are changed by two groups of little plants called *bacteria* which oxidize the compounds, first into nitrites and then nitrates.[1]

Relation of Bacteria to Free Nitrogen. — It has been known since the time of the Romans that the growth of clover, peas, beans, and other legumes in soil causes that ground to become more favorable for growth of other plants. The reason for this has been discovered in late years. On the roots of the plants mentioned are found little swellings or nodules; in the nodules exist millions of bacteria, which take out nitrogen from the atmosphere and fix it so that it can be used by the plant; that is, they form nitrates for the plants to use. Only these bacteria, of all the living plants, have the power to take the free nitrogen from the air and make it over into a form that can be used by the roots. As all the compounds of nitrogen are used over and over again, first by plants, then as food for animals, eventually returning to the soil again, it is evident that any *new* supply of usable nitrogen must come by means of these nitrogen-fixing bacteria.



Tubercles containing the nitrogen-fixing bacteria.

[1] It has recently been discovered that under some conditions these bacteria are preyed upon by tiny one-celled animals living in the soil and are so reduced in num-

Rotation of Crops. — The facts mentioned above are made use of by careful farmers who wish to make as much as possible from a given area of ground in a given time. Such plants as are hosts for the nitrogen-fixing bacteria are planted early in the season. Later these plants are plowed in and a second crop is planted. The latter grows quickly and luxuriantly because of the nitrates left in the soil by the bacteria which lived with the first crop. For this reason, clover is often grown on land in which it is proposed to plant corn, the nitrogen left in the soil thus giving nourishment to the young corn plants. This is known as rotation of crops. The annual yield of the average farm may be greatly increased by this means.

Soil Exhaustion may be Prevented. — Besides the rotation of crops, other methods are used by the farmer to prevent the exhaustion of raw food material from the soil. One method known as *fallowing* is to allow the soil to remain idle until bacteria and oxidation have renewed the chemical materials used by the plants. This is an expensive method, if land is dear. The most common method of enriching soil is by means of fertilizers, material rich in plant food. Manure is most frequently used, but many artificial fertilizers, most of which contain nitrogen, are used, because they can be more easily transported and sold. Such are ground bone, guano (bird manure), nitrate of potash, and many others. These contain as well other important raw food materials for plants, especially potash and phosphoric acid. Both of these substances are made soluble so as to be taken into the roots by the action of the carbon dioxide in the soil.

Forms of Roots and their Relation to the Life of the Plant. — Roots assume various forms. The form or position of the root is usually dependent on the needs of the plant, the roots acting to help it succeed in certain localities.

Food Storage in Roots and its Economic Importance. — The use to the plant of the food stored in the taproot may be understood if we take up the life history of the parsnip. Such a plant produces no seed until near the end of the second year of its existence, its growth the first summer forming the root we use as food. After forming seeds the plant dies.

bers that they cannot do their work effectively. If then the soil is heated artificially or treated with antiseptics so as to kill the protozoa, the bacteria which escape multiply so rapidly as to make the land much richer than before.

The food stored in its root enables it to get an early start in the spring, so as to be better able to produce seeds when the time comes. Such plants live only under rather cool climatic conditions. Examples of other roots which store food are carrot, radish, yam, sweet potato, etc. This food storage in roots is of much practical value to mankind. Many of our commonest garden vegetables, as those mentioned above, and the beet, turnip, oyster plant, and many others are of value because of the food stored. The sugar beet has, in Europe especially, become the basis of a great industry.

Water Roots. — In the duckweed, a plant living in water, the roots are short and contain few root hairs. The water supply is so great that few root hairs have been called forth. The water hyacinth is another example of slight development of roots. The plant is buoyed up by the water and does not need strong roots to hold it firm.

Adventitious Roots. — Roots are often developed in unusual places. Roots coming out thus, as, for example, on the stem, are called *adventitious*. Such roots are developed along the stem of many climbing plants — for example, the roots of English ivy.

Some plants, as strawberry, couch grass, and many others, develop new plants by striking root at any point on the reclining stem where it touches the ground. This fact is made use of by practical gardeners in the layering of plants.

Couch grass, showing how the plant spreads by striking roots from a reclining stem.

Corn roots, showing prop roots developed at first node above ground.

Examine the Indian corn for another kind of adventitious roots. Here they serve as props for the tall stem. In the young seedlings of corn, notice how early these roots develop. Also notice the manner in which they arise on the stem.

Air Roots. — In tropical forests, where the air is always warm and moist, some plants have come to live above the soil on the trunks of trees, or in other places where they can get a favorable foothold. Such plants are called *epiphytes*, or air plants. The tropical orchid seen in our greenhouses is an example. Examine the roots of such a plant. Notice how thick they are. They are usually provided with a spongy tissue around the outside which has the function of absorbing water.

Parasitic Roots. — *A few plants live on other living plants, and develop by the aid of nourishment taken at their expense. Such a plant is called a parasite. The plant or animal on which the parasite lives is called the host.* The mistletoe is an example of a parasitic plant. An examination of its roots shows that they have bored their way into the stem of the host. These roots not only penetrate the bark, but push toward the center of the tree, taking nourishment from the cells there. The dodder is another seed-bearing plant which has this habit. Dodder produces from seed, but is unable to live alone after it has passed the seedling stage, and will die if it cannot find a suitable host. It is found on many common weeds, as jewelweed and goldenrod. Many of the lower plants live as parasites, among them being mildew, rusts, and smuts found on roses, grain, and corn.

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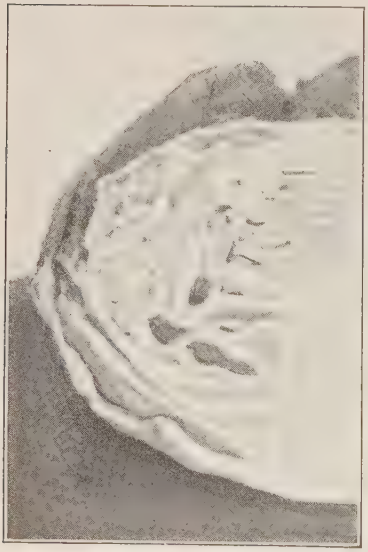
VIII. THE STRUCTURE AND WORK OF THE STEM

Problem XVI. *Relationship of buds to the growing plant (optional).* (*Laboratory Manual, Prob. XVI.*)

Structure of a Bud. — If we cut a head of cabbage through the long axis of its stem, we find that the stem is much shortened or dwarfed, and that the leaves are so placed as to cover it entirely. The cabbage is a big bud. If we carry out our definition of a bud, starting with what we have



A

B

A. Cabbage head cut lengthwise to show that it is a big bud. *B*. The bud under favorable conditions has grown into an elongated stem.

seen in the cabbage, we might say that a bud is a very much shortened branch, or, in reality, " the promise of a branch."

Factors which influence the Opening of a Bud. — A bud responds to the same stimuli that we have seen call a young plant into active life from the seed. If a branch containing unopened buds (such as horse-chestnut or willow) is placed in water in a moderately warm room, it will respond to the factors without it and begin to open. The tips of branches, still attached to the tree outdoors, may be introduced into a warm room through a hole bored in the window sash. They will open to bear flowers and leaves during the coldest months of the year. The factors which influence the germination of seeds also act on the bud.

Adaptations in the Bud of Horse-Chestnut. — If we now turn our attention to horse-chestnut buds which have been previously placed in water to open, we shall be able to get some notion of the wonderful adaptations of the bud which fit it for its work.

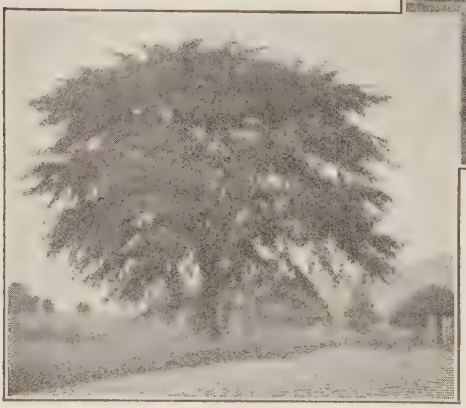
In the first place, a horse-chestnut bud is covered with a sticky material. Not only does this covering keep out unwelcome visitors which might bore into the bud and destroy the tender parts within, but it also serves as a waterproof covering against the icy rains of the late fall and early spring, and against evaporation in dry weather. In the unopened buds the scales overlap like shingles on a roof. In buds which have begun to open, we find that not only have the tiny green leaves been protected by the outer scales, but they have been additionally wrapped in soft, cottony substance. The young leaves are always folded or rolled up in the bud. Two purposes are thus served — protection from the elements and from drying by little exposure of the delicate surface, and economy of space by means of the tight and compact stowing away of the parts thus folded.

Opening bud of horse-chestnut: *L.*, leaves; *L.S.*, leaf scar; *S.*, scalelike leaves which cover bud.

Why Buds are Covered. — When we consider that most of our earliest green leaves come from opening buds in the early spring, the importance of a protective covering is well seen. Nevertheless, buds are frozen time and again during the cold

weather, only to thaw out again without injury to the plant. Sudden changes, however, do much harm. Some buds do not open during mild winter weather when temperature conditions are seemingly favorable; a definite length of growth seems in that case to be necessary. During warm weather plants give rise to buds which are devoid of protective scale leaves. Such is also noticed in tropical forms, which are not called upon to meet rigorous climatic conditions.

Position of the Bud on the Stem. — The growth of the stem from the bud can best be observed in a very young seedling. If, for example, we examine a pea seedling, it will be seen that the plumule or epicotyl is the first bud of the plant. It produces the first stem and leaves. Buds come out at the ends of branches (*terminal*) and at the sides (*lateral*).



A larch, an excurrent tree (at right) and an elm, a deliquescent tree (at left). Photographed by W. C. Barbour.

Deliquescent Tree. — The position of the most active buds determines the form of the future tree. If you examine a winter branch of the apple, elm, or oak tree, you will find that the lateral buds have developed more strongly and more rapidly than the terminal bud. Thus the tree has come to assume during its growth a rounded shape due to the rather more rapid development of the lateral buds. Such a tree, having a rather stout, short trunk, with many low, spreading, lateral branches, is said to be *deliquescent*.

Excurrent Tree. — If, on the other hand, the terminal buds of the tree get a better supply of light, food, or if other factors aid its growth, the tree will be tall and have but one main trunk, such as the Lombardy poplar, and pines and cedars. Such a tree is named *excurrent.* The picture shows trees of these two shapes.

Problem XVII. *The structure and work of stems.* (*Laboratory Manual, Prob. XVII.*)

(*a*) *External structure of a dicotyledonous stem* (*optional*).

(*b*) *Internal structure of a dicotyledonous stem.*

(*c*) *Circulation in stems.*

(*d*) *Condition of food passing through the stem.*

Three-year-old apple branch, showing terminal and lateral buds and bud scars.

The External Structure of a Dicotyledonous Stem. — A horse-chestnut twig in its winter condition shows the structure and position of the buds very plainly. As the twig grew last year the scales which covered the outside of the terminal bud dropped off, and the young shoot developed from the opened bud. The scales which dropped off left marks forming a little ring upon the surface of the twig. These rings, collectively named the *bud scars,* enable one to tell the age of the branch.

Just below the lateral buds are marks, known as *leaf traces,* that show the points at which leaves were attached. A careful inspection of the leaf traces reveals certain tiny dotlike scars arranged more or less in the form of a horseshoe. These scars mark the former position of bundles of tubes which we have already studied in connection with roots. They are, in fact, continuations of the same fibrovascular bundles which pass from the root up through the stem and out into the leaves, where we see them as the veins which act as the support of the soft green tissues of the leaf. *The most important use to the plant of the fibrovascular bundles is the conduction of fluids from the*

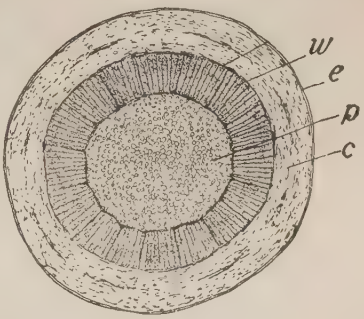
roots to the leaves and from the leaves to the stem and root. The arrangement of leaf traces on a branch gives us a clew as to the appearance of the leafy tree. If the leaf traces are oppositely placed, then we know that the leaves and buds, which give rise to lateral branches, had a very definite arrangement in pairs. Such are the maple or horse-chestnut. If, on the other hand, the leaf traces are placed alternate to each other, we can picture a tree with much less regularity in the position of leaves and lateral branches, as in the apple, beech, and elm.

Four years' growth in an ailanthus stem, showing the changes in the lenticels from round holes to elongated cracks in the bark. The lenticel in a young shoot is like the breathing hole of a leaf.

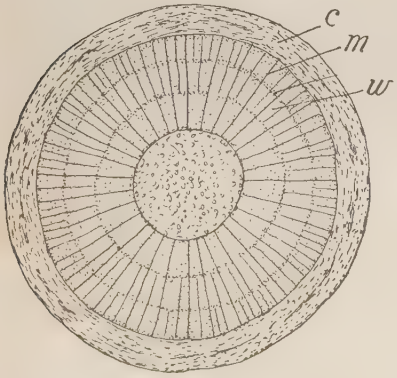
Lenticels and their Uses. — The very tiny scars, which look like little cracks in the bark, are very important organs, especially during the winter season, for they are the breathing holes of the tree. A tree is alive in winter, although it is much more active in the warm weather. Oxidation takes place much more rapidly in the summer because the plant is growing rapidly, and more fuel is consumed to release the energy needed for growth. We shall see later that the leaves are the chief breathing organs of the plant. But all the year round oxygen is taken in and carbon dioxide given off through the *lenticels*, as the breathing holes in the trunk and branches of a tree are called. The lenticels, which early in the life of the stem are structures similar to the breathing holes in leaves (of which more later), become quite changed in older stems, the tiny holes becoming cracklike scars.

A Dicotyledonous Stem in Cross Section. — If we cut a cross section through a young horse-chestnut stem, we find it shows three

distinct regions. The center is occupied by the spongy, soft *pith;* surrounding this is found the rather tough *wood,* while the outermost area is called *cortex* or *bark.* More careful study of the bark reveals the presence of three layers — an outer layer, a middle green layer, and an inner fibrous layer, the latter usually brown in color. This layer is made up largely of tough fiberlike cells known as *bast* fibers. The most important parts of this inner bark, so far as the plant is concerned, are many tubelike structures known as sieve tubes. These are long rows of living cells, having perforated sievelike ends. Through these cells food materials pass downward from the upper part of the plant, where they are manufactured.



Section across a young twig of box elder, showing the four stem regions: *e,* epidermis, represented by the heavy bounding line; *c,* cortex; *w,* wood; *p,* pith. (From Coulter, *Plant Relations.*)

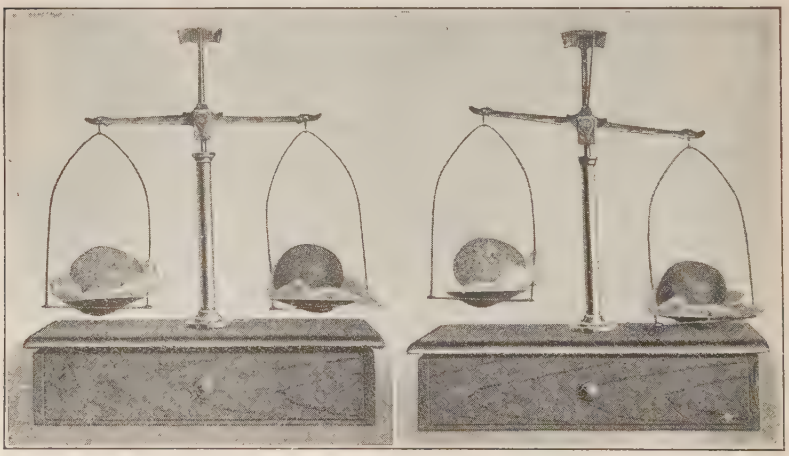


Section across a twig of box elder three years old, showing three annual growth rings in the vascular cylinder. The radiating lines (*m*), which cross the wood (*w*), represent the pith rays, the principal ones extending from the pith to the cortex (*c*). (From Coulter, *Plant Relations.*)

In the wood will be noticed (see Figure) a number of lines radiating outward from the pith toward the cortex. These are the so-called medullary rays, thin plates of pith which separate the wood into a number of wedge-shaped masses. These masses of wood are composed of many elongated cells, which, placed end to end, form thousands of little tubes connecting the leaves with the roots. In addition to these are many thick-walled cells, which give strength to the mass of wood. In sections of wood which have

taken several years to grow, we find so-called *annual rings*. The distance between one ring and the next (see Figure) usually represents the amount of growth in one year. Growth takes place from an actively dividing layer of cells, known as the *cambium layer*. This layer forms wood cells from its inner surface and bark from its outer surface. Thus new wood is formed as a distinct ring around the old wood.

Use of the Outer Bark. — The outer bark of a tree is protective. The cells are dead, the heavy woody skeletons serving to keep out

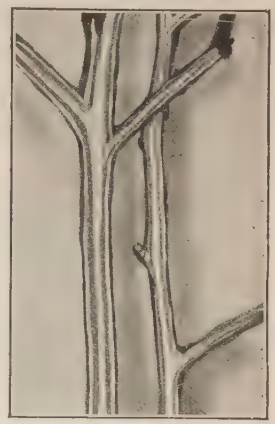


Experiment to show that the skin of the potato (a stem) retards evaporation.

cold and dryness, as well as prevent the evaporation of fluids from within. Most trees are provided with a layer of corky cells. This layer in the cork oak is thick enough to be of commercial importance. The function of the corky layer in preventing evaporation is well seen in the case of the potato, which is a true stem, though found underground. If two potatoes of equal weight are balanced on the scales, the skin having been peeled from one, the peeled potato will be found to lose weight rapidly. This is due to loss of water, which is held in by the skin of the unpeeled potato.

Passage of Fluids up and down the Stem.—If any young growing shoots (young seedlings of corn or pea, or the older stems of garden balsam, touch-me-not, or sunflower) are placed in red ink

(eosin), left in the sun for a few hours, and then examined, the red ink will be found to have passed up the stem. If such stems were examined carefully, it would be seen that the colored fluid is confined to the collections of woody tubes immediately under the inner bark. Water evidently rises in that part of the stem we call the wood.

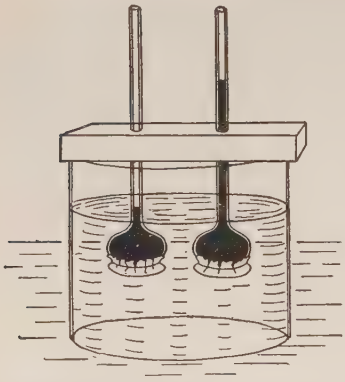


Apple twigs split to show the course of colored water up the stem.

But if willow twigs are placed in water roots soon begin to develop from that part of the stem which is under water. If now the stem is girdled by removing the bark in a ring just above where the roots are growing, the latter will eventually die, and new roots will appear above the girdled area. The food material necessary for the outgrowth of roots evidently comes from above, and the passage of food materials takes place in a downward direction just outside the wood in the layer of bark which contains the bast fibers and sieve tubes. Food substances are also conducted to a much less extent in the wood itself, and food passes from the inner bark to the center of the tree by way of the pith plates or medullary rays. This can be proved by testing for starch in the medullary rays of young stems. It is found that much starch is stored in this part of the tree trunk. This experiment with the willow explains why it is that trees die when girdled so as to cut the sieve tubes of the inner bark. The food supply is cut off from the protoplasm of the cells in the part of the tree below the cut area. Many of the canoe birches of our Adirondack forest are thus killed, girdled by thoughtless visitors.

In What Form does Food pass through the Stem? — We have already seen that materials in solution (those substances which will dissolve in the water) will pass from cell to cell by the process of osmosis. This is shown in the experiment illustrated on the following page. Two thistle tubes were partly filled, one with starch and water, the other with sugar and water, and a piece of parchment paper was tied over the end of each. The lower

end of both tubes was placed in a glass dish under water. After twenty-four hours, the water in the dish was tested for starch, and then for sugar. We find that only the sugar, which has been dissolved by the water, can pass through the membrane.



Experiment showing the osmosis of sugar (right-hand tube) and non-osmosis of starch (left-hand tube).

Digestion. — As we shall see later, the food for a plant is manufactured in the leaves or in stems, etc., wherever green coloring matter is found. Much of this food is in the form of starch. But starch, being insoluble, cannot be passed from cell to cell in a plant. It must be changed to a soluble form. This is accomplished by the process of *digestion*. We have already seen that starch was changed to grape sugar in the corn by the action of a substance (a digestive ferment) called *diastase*. This process of digestion seemingly may take place in all living parts of the plant, although most of it is done in the leaves. In the bodies of all animals, including man, starchy foods are changed in a similar manner, but by other digestive ferments, into soluble grape sugar. (See experiment, page 72.)

The food material may be passed in a soluble form until it comes to a place where food storage is to take place, then it can be transformed to an insoluble form (starch, for example); later, when needed by the plant in growth, it may again be transformed and sent in a soluble form through the stem to the place where it will be used.

Building of Proteids. — Another very important food substance stored in the stem is *proteid*. Of the building of proteid, little is known. We know it is an extremely complex chemical substance which is made in plants from compounds containing nitrogen, the nitrates and compounds of ammonia received through the roots from the organic matter contained in the soil, combined with sugar or starches in the body of the plant.

Some forms of proteid substance are *soluble* and others *insoluble*

in water. White of egg, for example, is very slightly soluble, but can be rendered insoluble by heating it so that it coagulates. Insoluble proteids are digested within the plant; how and where is but slightly understood. In a plant, soluble proteids pass down the sieve tubes in the bast and then may be stored in the bast or medullary rays of the wood in an insoluble form, or they may pass into the fruit or seeds of a plant, and be stored there.

What forces Water up the Stem. — We have seen that the process of osmosis is responsible for taking in soil water, and that the enormous absorbing surface exposed by the root hairs makes possible the absorption of a large amount of water. Frequently this is more than the weight of the plant in every twenty-four hours.

Experiments have been made which show that at certain times in the year this water is in some way forced up the tiny tubes of the stem. During the spring season, in young and rapidly growing trees, water has been proved to rise to a height of nearly ninety feet. *The force that causes this rise of water in stems is known as root pressure.*

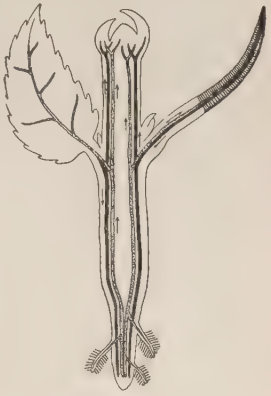


Diagram to show the areas in a plant through which raw food materials pass up the stem and food materials pass down. (After Stevens.)

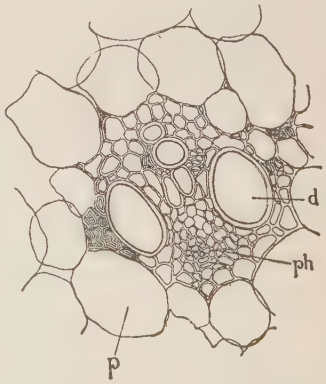
But root pressure alone cannot account for the rise of sap (water containing materials taken out of the soil) to a height of several hundred feet, as in the stems of the California big trees. Other forces must play a part here. One way in which the rise of water can be partly accounted for is in the fact that capillary attraction may help in part. If you place in a glass containing red or other colored fluid three or four tubes of different inside diameter, the fluid will be found to rise very much higher in the tubes having a smaller diameter. This is caused by capillarity or capillary attraction. When we consider that the tubes in the stem are *very* much smaller than any we can make out of glass, it can be seen that water *might* rise in the stem to some height in tubes of microscopic diameter.

The greatest factor, however, is one which will be more fully explained when we study the work of the leaf. Leaves pass off an immense quantity of water by evaporating it in the form of vapor. This evaporation seems to result in a kind of suction on the column of water in the stem. In the fall, after the leaves have gone, much less water is taken in by roots, showing that an intimate relation exists between the leaves and the root.

Structure of a Monocotyledonous Stem. — A piece of cornstalk examined carefully in cross and longitudinal section shows us that the main bulk of the stalk is made up of pith, while scattered through the pith are numerous stringy, tough structures. To these the name *fibrovascular bundles* has been given. The latter are the woody bundles of tubes which in this stem are scattered through the pith and run into the leaves at the nodes, where (in young specimens) they may be followed as veins. The outside of the corn stem is formed of large numbers of these bundles, which, closely packed together, form an outer *rind.* Thus the woody material gives mechanical support to an otherwise spongy stem.

Longitudinal section of cornstalk, showing some of the fibrovascular bundles passing outward at the node just above the roots.

Structure of Fibrovascular Bundle in a Monocotyledonous Stem. — A fibrovascular bundle in a cross section under the microscope shows this arrangement: Around the outside of the bundle is a collection of thick-walled, woody cells. These cells serve to support the bundle. Inside of these cells are found a number of tubes of different diameters, some for conduction of water, others for air, and still others for liquid food material sent down from the leaves. These tubes were formed by the elongation of certain cells of the bundle which in their growth have divided so as to form a string of cells. The contents of some of these cells die; a hollow tube of cellulose remains, which admits the passage of material from one level of the stem to another through the open ends of the cells. The conducting tubes have various functions. Some carry soil water and air up the stem, while others take food material down toward the roots. The bundles elongate rapidly, but are limited in their growth outward by the hard-walled, woody cells. An old stem of a monocotyledon contains more bundles than does a young stem, the bundles growing out as veins into the leaves.

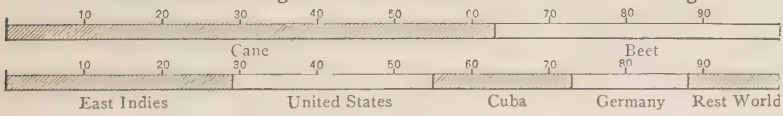


Monocotyledonous fibrovascular bundle: *ph*, region in which food passes down; *d*, woody portion or bundle ducts which carry air and water; *p*, pith cell.

Food Storage. — Many monocotyledonous trees which live for long periods of time store food in large quantities in the trunk. The sago palm is an example. The sugar cane is a monocotyledonous stem of great commercial value because of the sugar contained in its sap. Over 70 pounds of sugar on the average is used annually by each person in the United States. Most of the cane sugar grown in this country comes from Louisiana and Texas, although these states do not begin to supply the needs of this country. The diagram following graphically shows the sources and kinds of sugars used in the United States.

Palms and palmettos; typical monocotyledonous plants. Scene on Indian River, Florida.

Roots and Stems as Food. — Underground stems and roots form some of the most important sources of man's food supply. Our commonest foods, as the potato, sweet potato, onion, carrot, parsnip, turnip, and beet, are well-known examples. The sago palm is the



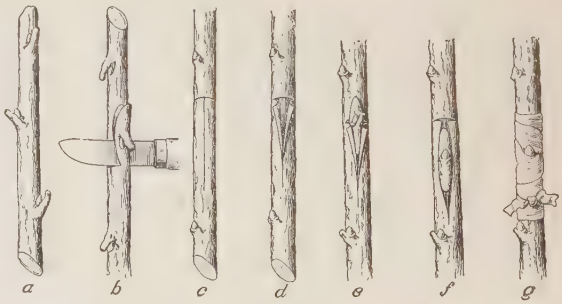
chief support of many of the natives of Africa. Each adult tree will furnish 700 pounds of sago meal, $2\frac{1}{2}$ pounds being enough to support a man one day. The cassava root, from which tapioca is made, is one of the main supports of African natives. Sugar, from the beet

root, is a world-known commodity, beet-sugar production having greatly increased in recent years. Maple sugar is a well-known commodity which is obtained by boiling the sap of sugar maple until it crystallizes. Over 16,000 tons of maple sugar is obtained every spring, Vermont producing about 40 per cent of the total output.

The following table shows the proportion of foods in some of the commoner roots and stems: —

	Water	Proteids	Carbohydrates	Fats	Ash
Potato	75	1.2	18	0.3	1.0
Carrot	89	.5	5	0.2	1.0
Parsnip	81	1.2	8.7	1.5	1.0
Turnip	92.8	.5	4.0	0.1	.8
Onion	91	1.5	4.8	0.2	.5
Sweet potato	74	1.5	20.2	0.1	1.5
Beet	82.2	.4	13.4	0.1	0.9

Budding. — We have said a bud is a promise of a branch; it may be more, the promise of a new tree. If the owner of an apple or peach tree wishes to vary the quality of fruit borne by the tree, he may in the early fall cut a T-shaped incision in the bark and then insert a bud surrounded with a little bark from the tree bearing the desired fruit.[1] The bud is bound in place and left over the winter. When a shoot from the embedded bud grows out the follow-



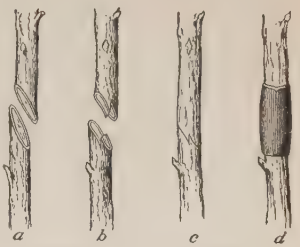
Steps in Budding.

(*a*) twig having suitable buds to use; (*b*) method of cutting out bud; (*c*) how the bark is cut; (*d*) how the bark is opened; (*e*) inserting the bud; (*f*) the bud in place; (*g*) the bud properly bound in place.

[1] This bud should be taken from a tree of the same species.

ing spring, it is found to have all the characters of the tree from which it was taken. This process is known as *budding*.

Grafting. — Of much the same nature is grafting. Here, however, a small portion of the stem of the closely allied tree is fastened into the trunk of the growing tree in such a manner that the two cut cambium layers will coincide. This will allow of the passage of food into the grafted part and insure the ultimate growth of the twig. Grafting and budding are of considerable economic value to the fruit grower, as it enables him to produce at will trees bearing choice varieties of fruit.[1]



Steps in tongue grafting.

(*a*) the two branches to be joined; (*b*) a tongue cut in each; (*c*) how fitted together; (*d*) method of wrapping.

In both of the above processes, the secret of successful growth lies in the fact that the cambium surface of the bud or the graft comes in contact with the cambium of the tree to which they are applied, thus putting them in direct communication with a supply of food from the already established tree.

Modified Stems. — We have seen in previous experiments, external forces may act on the organs of a plant so as to change its appearance and often its form and habit. A stem grown in complete darkness is white instead of green. The bleaching of the celery stems by covering them is a familiar example of this. Thus, in nature, forces which we know of as light, gravity, heat, moisture, wind, and perhaps other factors, influence the plant in its growth. Thus changes may take place which fit or adapt the parts of a plant better for life under certain conditions in which it must exist.

The potato tuber a stem; note the branches growing from the "eyes" at one end.

Stems modified for Water or Food Storage. — Many stems store large quantities of food. The sago palm is an example of such a stem. In most woody stems food is stored during some parts of the year and is used as the plant comes to need it. In

[1] For full directions for budding and grafting, see Goff and Mayne, *First Principles of Agriculture*, Chap. XIX, or Hodge, *Nature Study and Life*, pages 169–179.

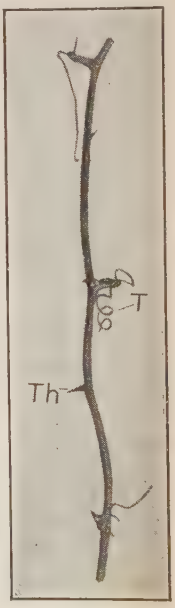
other stems the conditions of life are such that the plant has come to store water in the stem. The cactus, which we shall examine more in detail later, is a plant that has developed the stem for the storage of water, and is so adapted to desert conditions as to prevent the evaporation of water from the plant.

The potato tuber is simply a much thickened storage stem, as one may easily prove by examination of the so-called "eyes" of a sprouting potato. The tiny projection growing within the eye is a bud, which may give rise to a branch later. Food and water are stored with the tuber.

Longitudinal section of a lily bulb. Note the much thickened leaves, and the flower cluster at the center. Photographed by Overton.

Underground Stems; the Rootstock. — Other stems not only contain stored food, but run underground for the protection of the plant. Such a stem is the rootstock of the iris. Some underground stems do not store food, but grow with considerable rapidity, thus covering ground and starting new outposts of the plant at a distance from the original plants. The pest called quick grass or couch grass, found in almost every lawn, has such a stem. It may be cut in pieces, but each piece may strike root, thus multiplying the plant.

Bulbs. — In the bulb of a lily or the onion the stem is covered with thickened leaves, the whole making a compact and reduced plant which, because of its stored food, enables the plant to make an early start in the spring.



Catbrier; the tendrils (*T*) are modified stipules (parts of leaves); *Th*, thorn.

Reduced Stems. — In some plants the stem is so reduced as to be almost lost. This may be of a distinct advantage to the plant in enabling it to escape destruction from enemies. Such a plant is the common dandelion, which, because of its short stem, escapes grazing animals and the knives of lawn mowers. Many other low-lying weeds are partly immune from dangers which beset taller plants.

Climbing Stems. — Stems may twist around an object in order to climb. Such a plant is the morning-glory. Here the stimulus which draws the

plant upward is evidently the sun. In stems which make use of this method of climbing, it is noticed that each stem twines around the support in a given direction, some revolving with the course of the sun, others in the opposite direction. When such a stem touches an object during its first growth, it is immediately stimulated to turn toward the object and coil around it.

Leaves and Stems modified as Holdfasts. — In the common nasturtium (*tropæolum*) the leaves revolve in much the same manner as do the stems mentioned above. This movement results in some of the leafstalks fastening around supports, thus drawing the stem up.

Tendrils. — In some plants definite climbing organs, known as tendrils, are developed. A tendril, which has the appearance of a much twisted stem, may be modified from part of a leaf, as an entire leaf, or as part of a branch. Tendrils have the habit of at first stretching out as far from the main stem as possible, then slowly revolving. After a support is touched they immediately coil around it and then begin to curl up somewhat after the manner of a watch spring. This draws up the stem of which they are a part to the support.

A honey locust; the thorns are modified branches.

Stems modified as Thorns. — Leaves and parts of leaves may be changed into thorns for the protection of the plant. In some instances the stem becomes a spine or thorn. Such is the case in the honey locust.

In the case of the black locust, a part of the leaf, the stipule, becomes the thorn. All such modifications seem to result in the better protection of tender parts which might otherwise suffer from the attack of browsing animals.

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IX. LEAVES AND THEIR WORK

Problem XVIII. *A study of leaves in relation to their environment.* (*Laboratory Manual, Prob. XVIII.*)

(*a*) *Reactions of stems and leaves to light.*

(*b*) *Structure.*

(*c*) *Important functions.*

(*1*) *Food-making and its by-product.*

(*2*) *Evaporation of excess water.*

(*3*) *The leaf as a mill* (*optional*).

(*4*) *Absorption and respiration.*

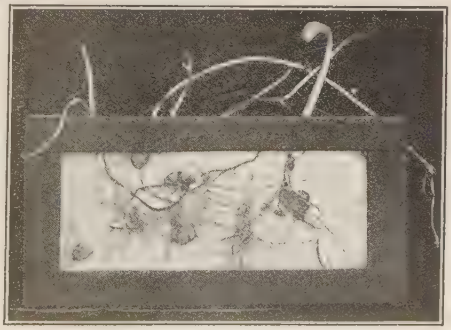
(*d*) *Means of protection* (*optional*).

(*e*) *Some leaf modifications* (*optional*).

(*f*) *Importance to man.*

Differences between Roots and Stems. — A comparison of the young root and developing stem of a bean seedling show that several marked differences exist: (1) the color of the stem is greenish, while the roots are gray or whitish; (2) the stem has leaves and branches leaving it in a more or less regular manner, while the smaller roots are extremely irregular in their method of growth; (3) the stem grows upward, while the general direction taken by the roots is downward.

Effect of Light on Plants. — In young plants which have been grown in total darkness, no green color is found in either stems or leaves, the latter often being reduced to mere scales. The stems are long and more or less reclining. We can explain



A pocket garden which has been kept in complete darkness for several weeks. Notice the bleached condition of stems and leaves.

the changed condition of the seedling grown in the dark only by assuming that light has some effect on the protoplasm of the seedling and induces the growth of the green part of the plant. Numerous instances could be given in which plants grown in sunlight are healthier and better developed as to their green parts than those in the shady parts of a garden or field. On the other hand, some plants thrive in the shade. Such plants are the mosses and ferns. Still other plants, minute organisms hardly visible to the eye, do not thrive in the light, and may be killed by its influence. Such are molds, mildews, and some bacteria. Such plants, however, are not green. As a

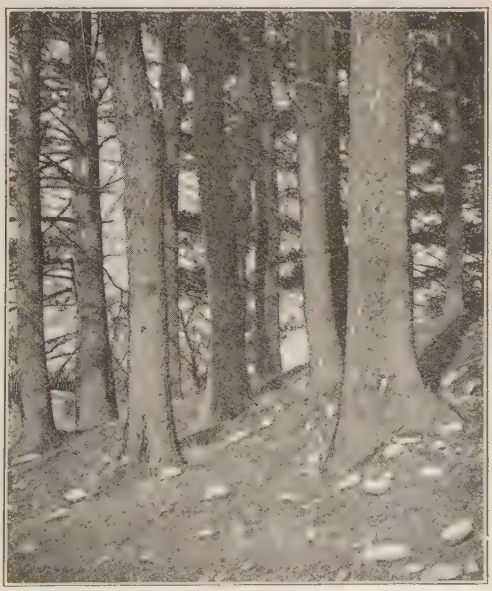
The growth of young stems and leaves of oxalis toward the light.

Two stages in an experiment to show that green plants grow toward the light.

matter of fact, the stem of a green plant which has but little chlorophyll develops somewhat more rapidly under conditions where it receives no light.

Heliotropism. — We saw that the stems of the plants kept in the darkness did not always lift themselves erect, as in the case of stems in the light. If seedlings have been growing on a window sill, or where the light comes in from one side, you have doubtless noticed that the stem and leaves of the seedlings incline in the direction from which the light comes. *The tendency of young stems and leaves to grow toward sunlight is called positive heliotropism.*

The experiment pictured on the preceding page shows this effect of light very plainly. A hole was cut in one end of a cigar box and barriers were erected in the interior of the box so that the seeds planted in the sawdust received their light by an indirect course. The young seedling in this case responded to the influence of the stimulus of light so as to grow out finally through the hole in the box into the open air. This growth of the stem to the light is of very great importance to a growing plant, because, as we shall see later, food-making depends largely on the amount of sunlight the leaves receive.



Tall straight stems of the hemlock; the trees reach up toward the source of light.

Effect of Light. — We have already found that seedlings grown in total darkness are almost yellow-white in color, that the leaves are but slightly developed, and that the stem has developed far more than the leaves. We have also seen that a green plant will grow toward the source of light, even against great odds. It is a matter of common knowledge that green leaves turn toward the light. Place growing pea seedlings, oxalis, or any other plants of rapid growth near a window which receives

full sunlight. Within a short time the leaves are found to be in positions to receive the most sunlight possible.

Arrangement of Leaves. — A study of trees in any park, or in the woods, shows that the stems of trees in thick forests are usually tall and straight and that the leaves come out in clusters near the top of the tree. The leaves lower down are often smaller and less numerous than those near the top of the tree. Careful observation of any plant growing outdoors shows us that in almost every case the leaves are so disposed as to get much sunlight. The ivy

A lily, showing long, narrow leaves.

The dandelion, showing a whorled arrangement of long, irregular leaves.

climbing up the wall, the morning-glory, the dandelion, and the burdock all show different arrangements of leaves, each presenting a large surface to the light. Leaves are usually definitely arranged, fitting in between one another so as to present their upper surface to the sun. Such an arrangement is known as a *leaf mosaic*. Good examples of such mosaics, or leaf patterns, are seen in trees having leaves which come up alternately, first on one side of a branch, then on the other. Here the leaves turn, by the twisting of their stalks, so that all the leaves present their upper surface to the sun. In the case of the dandelion, a rosette or whorled cluster of leaves is found. In the horse-chestnut, where the leaves come out opposite each other, the older leaves have longer petioles than the

young ones. In the mullein the entire plant forms a cone. The old leaves near the bottom have long stalks, and the little ones near the apex come out close to the main stalk. In every case each leaf receives a large amount of light. Other modifications of these forms may easily be found on any field trip.

The Sun a Source of Energy. — We all know the sun is a source of most of the energy that is released on this earth in the form of heat or light. Solar engines have not come into any great use as yet, because fuel is cheaper. Actual experiments have shown that vast amounts of energy are given to the earth. When the sun is in the zenith, energy equivalent to one hundred horse power is received by a plot of land twenty-five by one hundred feet, the size of a city lot. Plants receive and use much of this energy by means of their leaves.

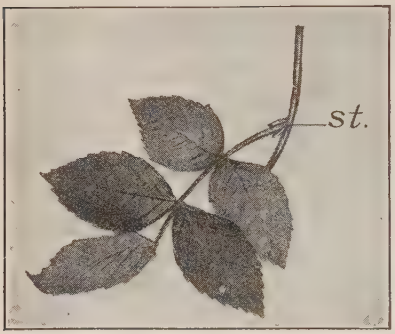
The Structure of a Leaf. — Let us now examine with some detail the structure of a simple leaf of a dicotyledonous plant.

A green leaf shows usually (1) a flat, broad *blade* which may take almost any conceivable shape; (2) a stem or *petiole* which (3) spreads out in the blade in a

Palmately-veined leaf of the maple.

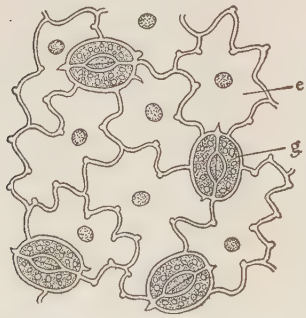
The skeleton of a netted-veined leaf: *M.R.*, midrib; *P.*, the leafstalk or petiole; *V.*, the veins.

number of *veins*. These veins usually present a netted appearance in the leaf of a dicotyledon, but run more or less parallel to one another in the blade of a monocotyledonous leaf. At the base of the leaf may be found a pair of outgrowths from the petiole called *stipules*. By means of these stipules in the rose leaf, for example, we are able to know that the leaf is compound, that is, each of the little leaflike parts is in reality part of a leaf blade that is so deeply indented that the blade is cut away to the *midrib*, or central vein, of the leaf — for a pair of stipules is found at the base of every complete leaf. These fall off early in many leaves.

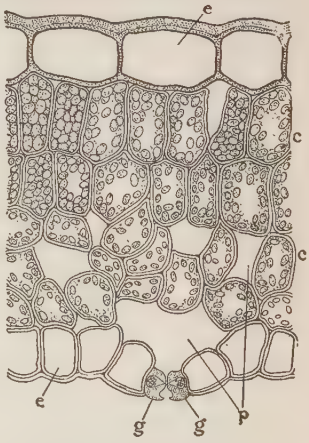


Pinnately-compound leaf of rose, showing stipules (*st*).

The Cell Structure of a Leaf. — The under surface of a leaf seen under the microscope usually shows numbers of tiny oval openings. These are called *stomata* (singular *stoma*). Two cells, usually kidney-shaped, are found, one on each side of the stoma. These are the *guard*



Surface view of epidermis of lower surface of a leaf; *e*, ordinary epidermal cell; *g*, guard cell. — Tschirch.



Section of a leaf; *e*, epidermis; *c*, cells containing chlorophyll bodies; *p*, intercellular passages; *g*, *g*, guard cells of stoma.

cells. By change in shape of these cells the opening of the stoma is made larger or smaller. Larger irregular cells form the *epidermis*, or outer covering of the leaf. Study of the leaf in cross section shows that these stomata open directly into air chambers which penetrate between and around the loosely arranged cells composing the underpart of the leaf. The upper surface of leaves sometimes contains stomata, but more often they are lacking. The under surface of an oak leaf of ordinary size contains about 2,000,000. Under the upper epidermis is a layer of green cells closely packed together (called collectively the *palisade layer*). These cells are more or less columnar in shape. Under these are several rows of rather loosely placed cells just mentioned. These are called collectively the *spongy parenchyma.* If we happen to have a section cut through a vein, we find this composed of a number of tubes made up of, and strengthened by, thick-walled cells. The veins are evidently a continuation of the tubes of the stem out into the blade or the leaf.

A hydrangea plant, upon the leaves of which disks of cork have been pinned in order to exclude sunlight from the leaf.

Starch made by a Green Leaf. — If we examine the palisade layer of the leaf, we find cells which are almost cylindrical in form. In the protoplasm of such cells are found a number of little green colored bodies, which are known as *chloroplasts* or *chlorophyll bodies.* If we place the leaf in wood alcohol, we find that the bodies still remain, but that the color is extracted, going into the alcohol and giving to it a beautiful green color. The chloroplasts are, indeed, simply part of the protoplasm of the cell colored green. If the plant is kept in the sun, the chloroplasts keep their green color, but in the dark this color is gradually lost. These bodies are of the greatest importance directly to plants and indirectly to animals.

The chloroplasts, by means of the energy received from the sun, manufacture starch out of certain raw materials. These raw materials are soil water, which is passed up through the bundles of tubes into the veins of the leaf from the roots, and carbon dioxide, which is taken in through the stomata or pores, which dot the under surface of the leaf.

Light and Air necessary for Starch-Making. — If we pin strips of black cloth, such as alpaca, over some of the leaves of a growing geranium, place the plant in a sunny window for two or three days, and then remove some of the covered leaves after a day of bright sunlight, we find after extracting the chlorophyll with wood alcohol (because the chlorophyll covers up the contents of the cells) that starch is present only in the portions of the leaves exposed to sunlight. From this experiment we infer that the sun has something to do with starch-making in a leaf. The necessity of air for starch-making may also easily be proved, for the parts of leaves covered with vaseline will be found to contain no starch, while parts of the leaf unvaselined but exposed to the sun and air contain starch.

Starchless areas in leaves caused by excluding sunlight by means of strips of black cloth.

Air is necessary for the process of starch-making in a leaf, not only because carbon dioxide gas is absorbed (there are from three to four parts in ten thousand present in the atmosphere), but also because the protoplasm of the leaf is alive and must have oxygen. This it takes from the air around it.

Comparison of Starch-Making and Milling. — The manufacture of starch by the green leaf is not easily understood. The process has been compared to the milling of grain. In this case the mill is the green part of the leaf. The sun furnishes the motive power, the chloroplasts constitute the machinery, and soil water and carbon dioxide are the raw products taken into the mill. The manufactured

product is starch, and a certain by-product (corresponding to the waste in a mill) is also given out. This by-product is oxygen. To understand the process fully, we must refer to a small portion of the leaf. Here we find that the cells of the green layer of the leaf, under the upper epidermis, perform most of the work. The carbon dioxide is taken in through the stomata and reaches the green cells by way of the intercellular spaces and by diffusion from cell to cell. Water reaches the green cells through the tracheal tubes of the veins. It then passes into the cells by osmosis, and there becomes part of the cell sap. The light of the sun easily penetrates to the cells of the palisade layer,

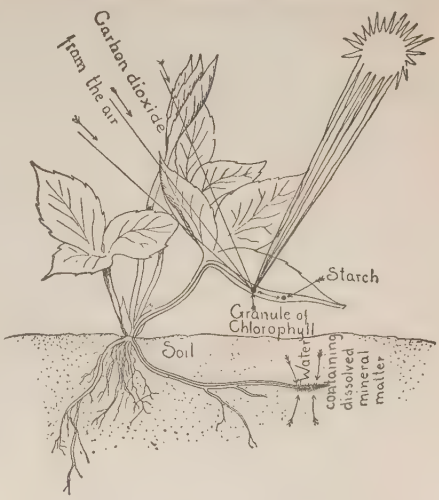


Diagram to illustrate the formation of starch.

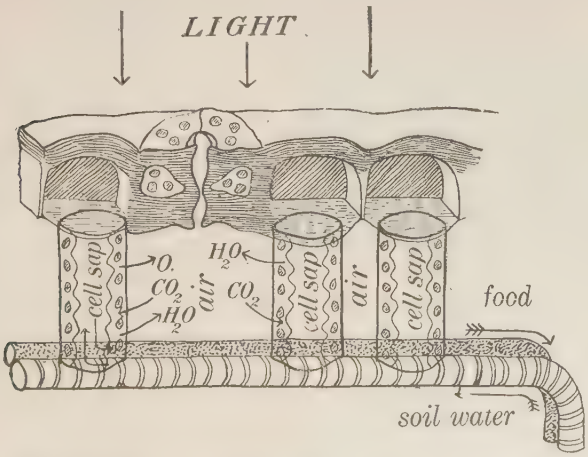


Diagram (after Stevens) to illustrate the processes of breathing, food-making, and transpiration which may take place in the cells of a green leaf in the sunlight.

giving the energy needed to make the food. This whole process is a very delicate one, and will take place only when external conditions are favorable. For example, too much heat or too little heat stops starch-making; the presence of stored food in the leaf, or of too much carbon dioxide in the atmosphere, may stop its work. This building up of food and the release of oxygen by the plant in the presence of sunlight is called *photosynthesis*.

Chemical Action in Starch-Making. — In the process of starch-making in a leaf, water (H_2O) and carbon dioxide (CO_2) are combined in such a way as to make starch, the molecule of which is expressed by the formula $C_6H_{10}O_5$. This combination is expressed as follows: $5\ H_2O + 6\ CO_2 = C_6H_{10}O_5 + 12\ O$. The starch thus formed is either stored in the leaf or changed by digestion to some form which can pass by osmosis from cell to cell; that is, a soluble material like grape sugar. The oxygen is passed off through the stomata of the leaf.[1]

An example of how a tree may exert energy. This rock has been split by the growing tree.

Proteid-Making and its Relation to the Making of Living Matter. — Proteid material is a food which is necessary to form protoplasm. Proteid food is present in the leaf, and is found in the stem or root as well. Proteids can apparently be manufactured in any plant cells, the presence of light not seeming to be a necessary factor. How it is manufactured is a matter of conjecture. The minerals brought up in the soil water form part of its composition, and starch or grape sugar give three elements. The element nitrogen is taken up by the roots as a nitrate (nitrogen in combination with lime or

[1] It seems probable that food material is first made in the form of a *sugar*, then changed to starch; when transported from one part of the plant to another, it is changed back to sugar.

potash). Proteids are probably not made directly into protoplasm in the leaf, but are stored by the cells of the plant and used when needed, either to form new cells in growth or to repair waste. While plants and animals obtain their food in different ways, they probably make it into living substance (*assimilate* it) in exactly the same manner.

Foods serve exactly the same purposes in plants and in animals; they either build living matter or they are burned (oxidized) to furnish energy (work power). If you doubt that a plant exerts energy, note how the roots of a tree bore their way through the hardest soil, and how stems or roots of trees often split open the hardest rocks, as illustrated on the opposite page.

Rapidity of Starch-Making. — Leaves which have been in darkness soon show starch to be present when exposed to light. Squash leaves make three fourths of an ounce for each square yard of surface. A corn plant sends 10 to 15 grams of reserve material into the ears in a single day. The formation of fruit, and especially the growth of the grain fields, show the economic importance of this fact. Not only do plants make their own food and store it away, but they make food for animals as well. And the food is stored in such a stable form that it may be sent to all parts of the world in the form of grain or other fruits. Animals, herbivorous and flesh-eating, man himself, all are dependent upon the starch-making processes of the green plant for the ultimate source of their food.

Experiment to show that oxygen is given off by green plants in the sunlight. *O*, oxygen.

Oxygen given off by Green Plants. — It is possible to prove that oxygen is given off by green plants in sunlight. The common green frog scum seen in shallow ponds is often so full of bubbles that it is buoyed up by this means at

the water's surface. If some of this plant or other green water weed is placed in a large battery jar or fruit jar in a sunny window, bubbles of gas will be seen to arise from it, the amount increasing as the water is warmed by the sun's rays.

If a glass funnel is placed upside down so as to cover the plants, and then a test tube full of water inverted over the mouth of the funnel, the gas may be collected by displacement. After two or three days of hot sun, enough of the gas can be obtained to make the oxygen test.

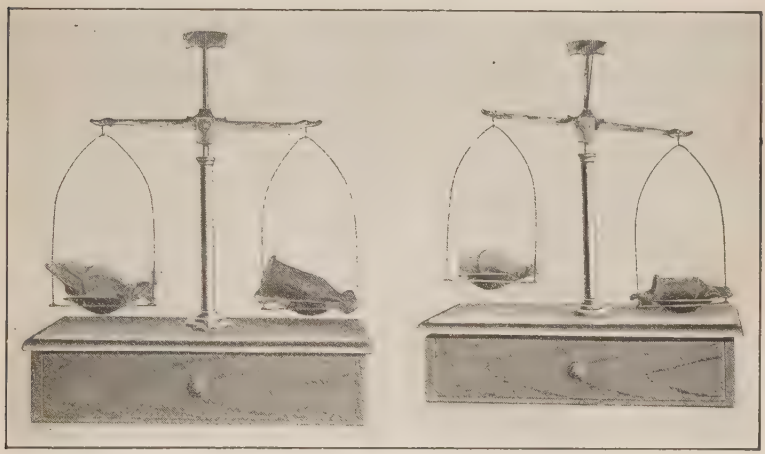
That oxygen is given off as a by-product by green plants is a fact of far-reaching importance. Parks are in a city true "breathing spaces." The green covering of the earth is giving to animals an element that they must have, while the animals in their turn are supplying to the plants carbon dioxide, a compound used in food-making. Thus a relation of mutual helpfulness exists between plants and animals.

Experiment to show transpiration. Notice that roots covered with root hairs have grown out of the main stem of the plant in response to the moist condition existing outside of the rubber-covered flower-pot and within the bell jar.

Evaporation of Excess Water. — In the manufacture of starch and proteid, an enormous amount of water is taken up by the roots and passed to the leaves to supply the needed amount of mineral matter. The excess of water is evaporated through the stomata. That water is passed through the blade of the leaf in the form of moisture is shown by the photograph above, drops of water having gathered on the inside of the bell jar. A small grass plant on a summer's day evaporates more than its own weight in water. This would make nearly half a ton of water

distributed to the air during twenty-four hours by a grass plot twenty-five by one hundred feet, the size of the average city lot. According to Ward, an oak tree may pass off two hundred and twenty-six times its own weight in water during the season from June to October.

From which Surface of the Leaf is Water Lost? — In order to find out whether water is passed out from any particular part of the leaf, we may remove two leaves of the same size and weight from some large-leaved plant — a mullein was used for the illustrations given below — and cover the



Experiment to show through which surface of a leaf water passes off.

upper surface of one leaf and the lower surface of the other with vaseline. The petioles of each should be covered with wax or vaseline, and the two leaves exactly balanced on the pans of a balance which has previously been placed in a warm and sunny place. Within an hour the leaf which has the upper surface covered with vaseline will show a loss of weight. Examination of the surface of a mullein leaf shows us that the lower surface of the leaf is provided with stomata. It is through these organs, then, that water is passed out from the tissues of the leaf.

Regulation of Transpiration. — The stomata of leaves close at night. On days when there is little humidity, they also tend to close, retarding transpiration, but when the water supply is abundant they open, increasing transpiration. This automatic action is of very great importance to the life of a plant, since evaporation of water is thus regulated.

The Effect of Transpiration on Water within the Stem. — It has already been noted that root pressure alone will not account for the rise

of water to the tops of very tall trees. Experiments show that evaporation of water through the stomata exerts a lifting power upon the fluids within the stem of the tree, thus aiding in the raising of water to the leaves in the upper branches.

a *b* *c*

Diagrams of a stoma: *a*, surface view of an opened stoma; *b*, same stoma closed (after Hansen); *c*, diagram of a transverse section through a stoma — dotted lines indicate the closed position of the guard cells, the heavy lines the open condition. (After Schwendener.)

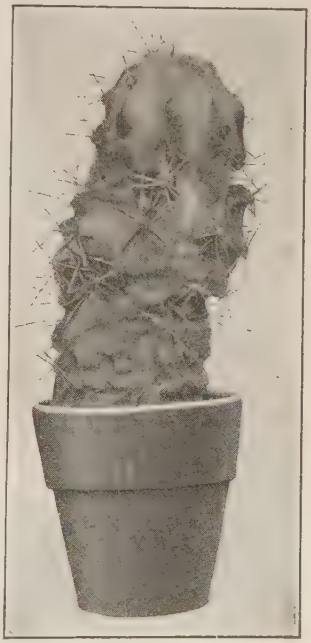
Respiration by Leaves. — All living things require oxygen. It is by means of the oxidation of food materials within the plant's body that the energy used in growth and movement is released. A plant takes in oxygen largely through the stomata of the leaves, to a less extent through the lenticels in the stem, and through the roots. Thus rapidly growing tissues receive the oxygen necessary for them to perform their work. The products of oxidation in the form of carbon dioxide are also passed off through these same organs. It can be shown by experiment that a plant uses up oxygen in the darkness; in the light the amount of oxygen given off as a by-product in the process of starch-making is, of course, much greater than the amount used by the plant.

Summary. — From the above paragraphs it is seen that a leaf performs the following functions: (1) breathing, or the taking in of oxygen and passing off of carbon dioxide; (2) starch-making, with the incidental passing out of oxygen; (3) formation of proteids, with their digestion and assimilation to form new tissues; and (4) the transpiration of water.

Economic Uses of Leaves. — The practical use of green plants to man is very great. Plants give off oxygen in the sunlight and use carbon dioxide, which is given off by animals in the breath. We should remember, as taxpayers, that money invested in public parks is money well invested, bringing as it does a source of oxygen supply where it is most needed, in the congested parts of our great cities.

Another very important use to man is seen in the fact that leaves, falling to the ground, help to form a rich covering of humus, which acts as a coat to hold in moisture. The forests are our greatest source of water supply. The cutting away of the forest always means a depletion of the reserve water stored in soil, with consequent floods and droughts in alternation.

Leaves are used directly by man for food. Examples are cabbage, lettuce, kale, broccoli, and some others. These foods, properly admixed with certain fleshy foods, are of great importance in giving a balance to diet. In a wider sense, all animals depend upon leaves for their food supply either directly, — for herbivorous animals feed upon the leaves of plants — or indirectly in foods obtained from roots, stems, seeds, and fruits. For in every case the stored food has been manufactured in the leafy part of the plant and transported within the plant to its place of storage. Even meat-eating animals are in the long run dependent upon plants, for they feed upon plant eaters.



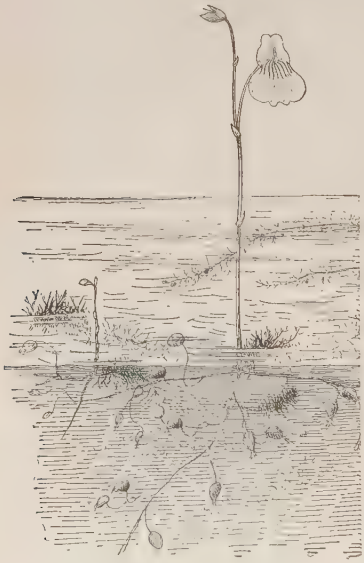
A cactus, showing the leaves modified into spines.

Modified Leaves. — In many plants the leaves are reduced to spines or have part of the leaf modified so as to form spines. In some leaves this appears to be for protection against animals, but in some cases, as the cactus, it is a means of protecting the plant against loss of water through evaporation.

If a cactus is cut open, it will be found to contain a very considerable amount of water. The Indians of the New Mexican desert region, when far from a source of water, sometimes cut off the top of a large cactus, mash up the soft interior of the thickened stem, squeeze out the pulp, and thus obtain several quarts of drinkable water.

Protection by Hairs. — In the mullein, one of our hardiest weeds, the leaf is covered with a coating of finely branched hairs. Might such a covering be of use to the leaf? In what ways?

Storage of Food and Water in Leaves. — Leaves may be modified for the storage of food and water. Test an onion, which is a collection of thickened leaves closely wrapped to form what is called a bulb, for starch, sugar, and proteid. Squeeze any fleshy leaves and notice the water contained in them. The agave is a desert plant in which the leaves have become greatly thickened as a water and food storage.



Bladderwort, showing finely dissected submerged leaves bearing blades which capture little animals.

Leaves modified for Use in Climbing. — Sometimes, as in the leaf of the pea, a part of the leaf is modified for the purpose of climbing. In this case a part of the leaf, called the tendril, becomes especially sensitive to the stimulus of touch, and upon touching an object slowly coils around it. Almost any part of the leaf, or indeed the entire leaf, may be modified to become a tendril.

Reduced Leaves. — Leaves may be reduced to scales or lost altogether. In the asparagus, what seem to be tiny leaves are branches which spring from the axils of the true, very tiny, scalelike leaves.

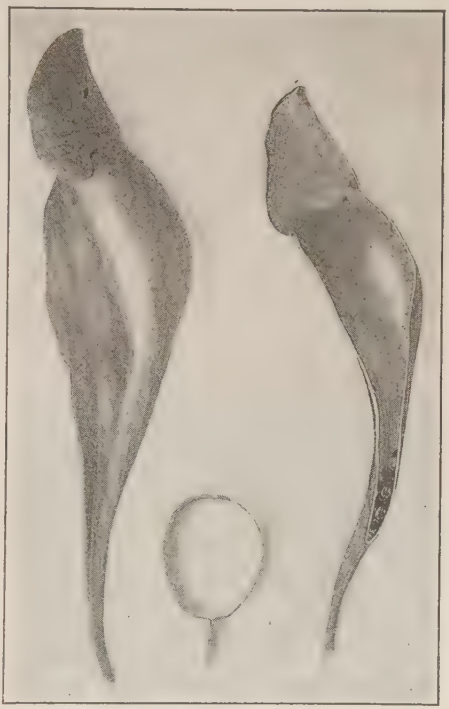
Leaves as Insect Traps. — Most curious of all are the modifications of the leaf into insect traps. It frequently happens that the habitat of a plant will not furnish the raw food materials necessary to form proteid food and to build protoplasm. Nitrogen is the lacking element. The plant has become adapted to these conditions and obtains nitrogenous food from the bodies of insects which it catches. Examples of insect traps are the common bladderwort (*utricularia*), the Venus's flytrap (*Dionœa muscipula*), the sundew (*Drosera rotundifolia*), and certain of the pitcher plants.

Leaf of sundew closing over captured insect.

Bladderwort. — The simplest contrivance for the taking of animal food by the leaf is seen in the bladderwort. Here certain of the leaves are modified into little bladders provided with trapdoors which open inwards. Small water-swimming crustaceans (as water fleas, etc.) push their way into the trap and there

die, perhaps of starvation. Bacteria, causing decay, soon break down their bodies into soluble substances, the nitrogenous portion of which is absorbed by the inner surface of the bladders and used by the plant as food.

Venus's Flytrap. — In the Venus's flytrap, a curious plant found in our Southern states, the apex of the leaf is peculiarly modified to form an insect trap. Each margin of the leaf is provided with a row of hairs; there are also three central hairs on each side of the midrib. The hairs are sensitive to a stimulus from without. The blade is so constructed that the slightest stimulus causes a closing of the leaf along the midrib. The surface of the leaf is provided with many tiny glands, which pour out a fluid capable of digesting proteid food. Thus an insect, caught between the halves of the leaf blade, is held there and slowly digested.



a *b* *c*

Pitcher plant: *a*, leaf; *b*, cross section; *c*, longitudinal section. Note the insects at the bottom, and the inward-pointing hairs at the top.

Sundew. — In the sundew the leaves are covered with long glandular hairs, each of which is extremely sensitive to the stimulus of any nitrogenous substance. These hairs exude a clear, sticky fluid which first renders more difficult the escape of the insect caught in the hairs, and then digests the nitrogenous parts of the insect thus caught.

Pitcher Plants. — The common pitcher plant has an urn-shaped leaf which is modified to hold water. Many small flies and other insects find their way into the pitcher and are eventually drowned in the cup. Whether the plant actually makes use of the food thus obtained is a matter unsettled, but some tropical forms undoubtedly do use the caught insects as food.

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X. OUR FORESTS; THEIR USES AND THE NECESSITY FOR THEIR PROTECTION

Problem XIX. *Some uses of stems (optional). (Laboratory Manual, Prob. XIX.)*

(a) Special product from stems.

(b) Some woods and their value.

(c) Field work in forestry.

The Economic Value of Trees. Protection and Regulation of Water Supply. — Trees form a protective covering for the earth's surface. They prevent soil from being washed away, and they hold moisture in the ground. Without trees many of our rivers might go dry in summer, while in the rainy season sudden floods would result. The devastation of immense areas in China and considerable damage by floods in parts of Switzerland, France, and in Pennsylvania has resulted where the forest covering has been removed. No one who has tramped through our Adirondack forest can escape noticing the differences in the condition of streams which flow through areas covered with forest and those from around which trees have been cut. The latter streams often dry up entirely in hot weather, while the forest-shaded stream has a never failing supply of crystal water.

Working to prevent erosion after the removal of the forest in the French alps.

The city of New York owes much of its importance to its position at the mouth of a great river with a harbor large enough to float the navies of the world. This river is supplied with water

largely by the Adirondack and Catskill forests. Should these forests be destroyed, it is not impossible that the frequent freshets which would follow would so fill the Hudson River with silt and debris that the ship channels in the bay, already costing the government millions of dollars a year to keep dredged, would become too shallow for ships. If this *should* occur, the greatest city in this country would soon lose its place and become of second-rate importance.

Erosion at Sayre, Penn., by the Chemung River. Photograph by W. C. Barbour.

The story of how this very thing happened to the old Greek city of Poseidonia is graphically told in the following lines: —

"It was such a strange, tremendous story, that of the Greek Poseidonia, later the Roman Pæstum. Long ago those adventuring mariners from Greece had seized the fertile plain which at that time was covered with forests of great oak and watered by two clear and shining rivers. They drove the Italian natives back into the distant hills, for the white man's burden even then included the taking of all the desirable things that were being wasted by incompetent natives, and they brought over colonists — whom the philosophers and moralists at home maligned, no doubt, in the same pleasant fashion of our own day. And the colonists cut down the oaks, and plowed the land, and built cities, and made harbors, and finally dusted their busy hands and busy souls of the grime of labor and wrought splendid temples in honor of the benign gods who had given them the possessions of the Italians and filled them with power and fatness.

"Every once in so often the natives looked lustfully down from the hills upon this fatness, made an armed snatch at it, were driven back with bloody contumely, and the heaping of riches upon riches went on. And more and more the oaks were cut down — mark that! for the stories of nations are so inextricably bound up with the stories of trees — until all the plain was cleared and tilled; and then the foothills were denuded, and the wave of destruction crept up the mountain sides, and they, too, were left naked to the sun and the rains.

"At first these rains, sweeping down torrentially, unhindered by the lost forests, only enriched the plain with the long-hoarded sweetness of the trees; but by and by the living rivers grew heavy and thick, vomiting mud into the ever shallowing harbors, and the land soured with the undrained stagnant water. Commerce turned more and more to deeper ports, and mosquitoes began to breed in the brackish soil that was making fast between the city and the sea.

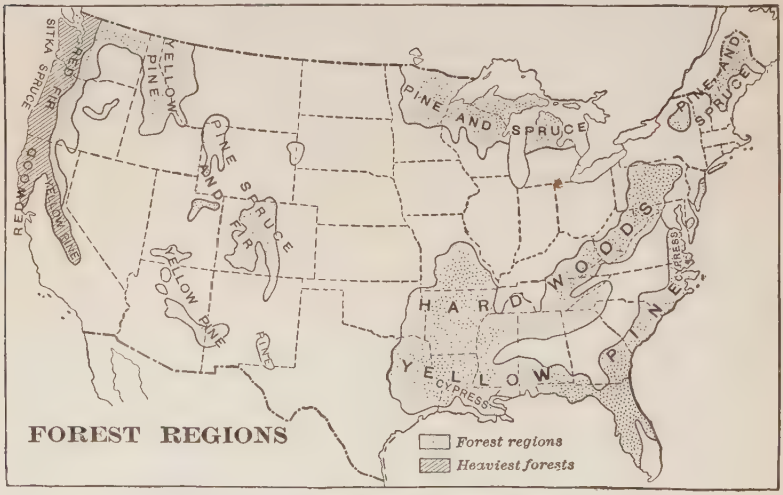
"Who of all those powerful landowners and rich merchants could ever have dreamed that little buzzing insects could sting a great city to death? But they did. Fevers grew more and more prevalent. The malaria-haunted population went more and more languidly about their business. The natives, hardy and vigorous in the hills, were but feebly repulsed. Carthage demanded tribute, and Rome took it, and changed the city's name from Poseidonia to Pæstum. After Rome grew weak, Saracen corsairs came in by sea and grasped the slackly defended riches, and the little winged poisoners of the night struck again and again, until grass grew in the streets, and the wharves crumbled where they stood. Finally, the wretched remnant of a great people wandered away into the more wholesome hills, the marshes rotted in the heat and grew up in coarse reeds where corn and vine had flourished, and the city melted back into the wasted earth."

Elizabeth Bisland and Anne Hoyt, *Seekers in Sicily*. John Lane Company.

Prevention of Erosion by Covering of Organic Soil. — We have shown how ungoverned streams might dig out soil and carry it far from its original source. Examples of what streams have done may be seen in the deltas formed at the mouths of great rivers. The forest prevents this by holding the water supply and letting it out gradually. This it does by covering the inorganic soil with humus or decayed organic material. In this way the forest floor becomes like a sponge, holding water through long periods of drought. The roots of the trees, too, help hold the soil in place. The gradual evaporation of water through the stomata of the leaves cools the atmosphere, and this tends to precipitate the moisture in the air. Eventually the dead bodies of the trees themselves are added to the organic covering, and new trees take their place.

Other Uses of the Forest. — In some localities forests are used as windbreaks and to protect mountain towns against avalanches. In winter they moderate the cold, and in summer reduce the heat and lessen the danger from storms. The nesting of birds in woods protects many plants valuable to man which otherwise might be destroyed by insects.

Forests have great commercial importance as well. Even in this day of coal, wood is still by far the most-used fuel. It is useful in building. It outlasts iron under water, in addition to being durable and light. It is cheap and, with care of the forests, inexhaustible, while our mineral wealth will some day be used up. Hard woods are chiefly used in house building and furniture manufacture; the soft woods, reduced to pulp, are made into paper. Distilled wood gives alcohol. Partially burned wood is charcoal. Vinegar and other acids are obtained from trees, as are tar, creosote, resin, turpentine, and other useful oils. The making of maple sirup and sugar forms a profitable industry in several states.



The forest regions of the United States.

The Forest Regions of the United States. — The combined area of all the forests in the United States, exclusive of Alaska, is about 500,000,000 acres. This seemingly immense area is rapidly decreasing in acreage and in quality, thanks to the demands of an increasing population, a woeful ignorance on the part of the owners of the land, and wastefulness on the part of cutters and users alike.

A glance at the map shows the distribution of our principal forests. The following figures taken from the United States Census reports tell their own tale. In 1908, 31,231 sawmills cut

33,289,369,000 feet of lumber. They also cut over 12 billion shingles and nearly 30 billion laths. Nobody can tell how much lumber was wasted, either in the forest or at the mill. The census estimates, moreover, that owing to conditions caused by the panic, the amount cut was very considerably under that cut in 1907. Washington ranks first in the production of lumber. Here the great Douglas fir, one of the "evergreens," forms the chief source of supply. In the Southern states, especially Louisiana and Mississippi, yellow pine and cypress are the trees most lumbered.

Uses of Wood. — In our forests much of the soft wood (the cone-bearing trees, spruce, balsam, hemlock, and pine), and poplars, aspens, basswood, with some other species, make paper pulp. The daily newspaper and cheap books are responsible for inroads on our forests which cannot well be repaired. It is not necessary to take the largest trees to make pulp wood. Hence many young trees of not more than six inches in diameter are sacrificed.

Transportation of lumber in the West. A logging train.

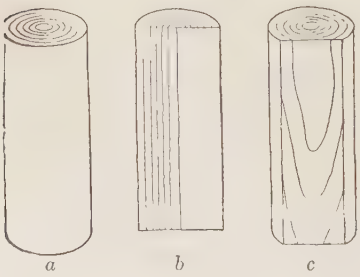
Of the hundreds of species of trees in our forests, the conifers are probably most sought after for lumber. Pine, especially, is probably used more extensively than any other wood. It is used in all heavy construction work, frames of houses, bridges, masts, spars and timber of ships, floors, railway ties, and many other purposes. Cedar is used for shingles, cabinetwork, lead pencils, etc.; hemlock and spruce for heavy timbers and, as we have seen, for paper pulp. Another use for our lumber, especially odds and ends of all kinds, is in the packing-box industry. It is estimated that nearly 50 per cent of all lumber cut ultimately finds its way into the construction of boxes. Hemlock bark is used for tanning.

The hard woods, ash, basswood, beech, birch, cherry, chestnut, elm, maple, oak, and walnut, are used largely for the "trim" of

Transportation of lumber in the East. Logs are mostly floated down rivers to the mills.

our houses, for manufacture of furniture, wagon or car work, and endless other purposes.

Structure of Wood. — Quite a difference in color and structure is often seen between the heartwood, composed of the dead walls of cells occupying the central part of the tree trunk, and the sapwood, the living part of the stem. In trees which are cut down for use as lumber and in the manufacture of various furniture, the markings and differences in color are not always easy to understand.



Diagrams of sections of timber: *a*, cross section; *b*, radial; *c*, tangential. (From Pinchot, U.S. Dept. of Agr.)

Methods of cutting Timber. — A glance at the diagram of the sections of timber show us that a tree may be cut radially through the middle of the trunk or tangentially to the middle portion. Most lumber is cut tangentially. Hence the yearly rings take a more or less irregular course. The grain of wood is caused by the

fibers not taking straight lines in their course in the tree trunk. In many cases the fibers of the wood take a spiral course up the trunk, or they may wave outward to form little projections. Boards cut out of such a piece of wood will show the effect seen in many of the school desks, where the annual rings appear to form elliptical markings.

Knots. — Knots, as can be seen from the diagram, are branches which at one time started in their outward growth and were for some reason killed. Later, the tree, continuing in its outward growth, surrounded them and covered them up. A dead limb should be pruned before such growth occurs. The markings in bird's-eye maple are caused by adventitious buds which have not developed, and have been overgrown with the wood of the tree.

Section of tree trunk showing knot.

Destruction of the Forest. *By Waste in Cutting.* — Man is responsible for the destruction of one of this nation's most valuable assets. This is primarily due to wrong and wasteful lumbering.

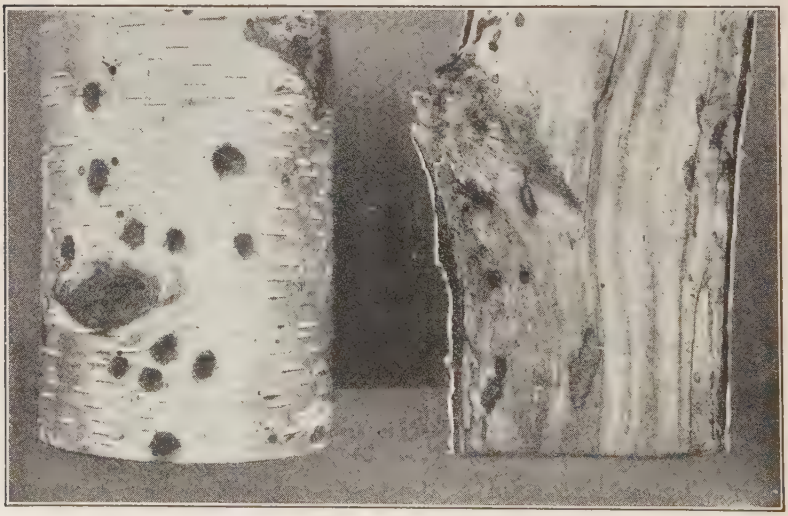
A forest in the far West totally destroyed by fire and wasteful lumbering.

Hundreds of thousands of dollars' worth of lumber is left to rot annually because the lumbermen do not cut the trees close enough to the ground, or because through careless felling of trees many other

smaller trees are injured. There is great waste in the mills. In fact, man wastes in every step from the forest to the finished product.

By Fire. — Indirectly, man is responsible for fire, one of the greatest enemies of the forest. Most of the great forest fires of recent years, the losses from which total in the hundreds of millions, have been due either to railroads or to carelessness in setting fires in the woods. It is estimated that in forest lands traversed by railroads from 25 per cent to 90 per cent of the fires are caused by coal-burning locomotives. For this reason laws have been made in New York state requiring locomotives passing through the Adirondack forest preserve to burn oil instead of coal. This has resulted in a considerable reduction in the number of fires. In addition to the loss in timber, the fires often burn out the organic matter in the soil (the "duff") forming the forest floor, thus preventing the growth of forest there for many years to come. In New York and other states fires are fought by an organized corps of fire wardens, whose duty it is to watch the forest and to fight forest fires.

Other Enemies. — Other enemies of the forest are numerous fungous plants of which we will learn more later, insect parasites,



Our birds help protect our forests. This tree has been attacked by boring insects, but woodpeckers have dug them out and killed them.

which bore into the wood or destroy the leaves, and grazing animals, particularly sheep. Wind and snow also annually kill many trees.

Forestry. — The American forests have long been our pride. In Germany, especially, the importance of the forest has long been recognized, and the German forester or caretaker of the forests is well known. In some parts of central Europe, the value of the forests was seen as early as the year 1300 A.D., and many towns consequently bought up the surrounding forests. The city of Zurich has owned forests in its vicinity for at least 600 years. In this country only recently has the importance of preserving and caring for our forests been noted by our government. Now, however, we have a Forest Service in the U. S. Department of Agriculture; and this and numerous state and university schools of forestry are rapidly teaching the people of this country the best methods for the preservation of our forests. The Federal Government has set aside a number of tracts of mountain forest in some of the Western states, making a total area of over 167,000,000 acres. New York has established for the same purpose the Adirondack Park, with nearly 1,500,000 acres of timber land. Pennsylvania has one of 700,000 acres, and many other states have followed their example.

Methods for Keeping and Protecting the Forests. — Forests should be kept thinned. Too many trees are as bad as too few. They struggle with one another for foothold and light, which only a few can enjoy. In cutting the forest it should be considered as a harvest. The oldest trees are the "ripe grain," the younger trees being left to grow to maturity. Several methods of renewing the forest are in use in this country. (1) Trees may be cut down and young ones allowed to sprout from cut stumps. This is called coppice growth. This growth is well seen in parts of New Jersey. (2) Areas or strips may be cut out so that seeds from neighboring trees are carried there to start new growth. (3) Forests may be artificially planted. Two seedlings planted for every tree cut is a rule followed in Europe. The greatest dangers are from fire and from careless cutting, and these dangers may be kept in check by the efficient work of our national and state foresters.

A City's Need for Trees. — All over the United States the city governments are beginning to realize what European

cities have long known, that trees are of great value to a city. Many cities are spending money not only for trees, but for proper means of protection. Thousands of city trees are annually killed by horses, which "crib" upon them. This may be prevented by proper protection of the trunk.

We must protect our city trees. A tree badly wounded by "cribbing" of horses.

Washington spent more than $37,000 for shade trees last year; Newark, N.J., $27,000; Springfield, Mass., $21,500; and St. Louis, $14,000. Chicago has appointed a city forester, who has given the following excellent reasons why trees should be planted in the city:—

(1) Trees are beautiful in form and color, inspiring a constant appreciation of nature.
(2) Trees enhance the beauty of architecture.
(3) Trees create sentiment, love of country, state, city, and home.
(4) Trees have an educational influence upon citizens of all ages, especially children.
(5) Trees encourage outdoor life.
(6) Trees purify the air.
(7) Trees cool the air in summer and radiate warmth in winter.
(8) Trees improve climate and conserve soil and moisture.
(9) Trees furnish resting places and shelter for birds.
(10) Trees increase the value of real estate.
(11) Trees protect the pavement from the heat of the sun.
(12) Trees counteract adverse conditions of city life.

Let us all try to make Arbor Day what it should be, a day for caring for and planting trees, for thus we may preserve this most important heritage of our nation.

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XI. THE VARIOUS FORMS OF PLANTS AND HOW THEY REPRODUCE THEMSELVES

Problem XX. *Some forms of plant life.* (*Optional.*) (*Laboratory Manual, Prob. XX.*)

(*a*) *An alga.*
(*b*) *A fungus.*
(*c*) *A moss.*
(*d*) *A fern.*

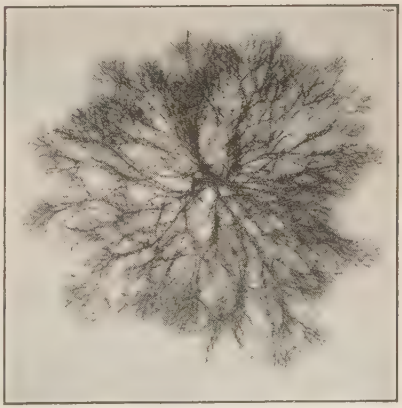
Simplest Plant Body a Thallus. — It has been found by botanists that the plants which are the simplest in body structure are those which live in the water. Sometimes such simple plants are found upon rocks or on the bark of trees. In such plants we can distinguish no root, stem, or leaf. The plant body may even be spherical in outline and consist of but a single cell. Such are the plants (*pleurococcus*) which give the green color to the bark of trees. Still other plants are threadlike in appearance. Others, as seaweeds, have a ribbon-shaped body. All these diverse shapes of plant body are grouped under the general name of *thallus*. *The simplest forms of plants have a thalluslike body.*

A red seaweed, an example of a thallus body.

Adaptation to Environment. — Plants, as well as animals, are greatly affected by what immediately surrounds them, their environment. We have shown in our experiments that the environment (conditions of temperature, moisture, soil, etc.) is capable of changing or modifying the structure of plants very greatly. *The changes which a plant or animal has undergone, that fit it for conditions in which it lives, are called adaptations to environment.*

The principal factors which act on plants and which make up their environment are soil, water, temperature, and light.

The first plants were probably water-loving forms. It seems likely that, as more land appeared on the earth's surface, plants became adapted to changed conditions of life on dry land. With this change in habit came a need of taking in water, of storing it, of conducting it to various parts of the organism. So it does not seem unlikely that plants came to have roots, stems, and leaves, and thus became adapted to their environment on dry land. We find in nature that those plants or animals which are best adapted or fitted to live under certain conditions are the ones which survive or drive other competitors out from their immediate neighborhood. Nature selected those which were best fitted to live on dry land, and those plants eventually covered the earth with their progeny. Eventually, the forms of life grew more and more complex until at last very complicated organisms such as the flowering plants came to live upon the earth. Between the flowering plant and the simplest of all plants are several great plant groups which act as steps in complexity of structure between the most lowly and the most highly specialized plants. The simplest of all these forms are the algæ.



A red seaweed, showing a finely divided thallus body.

Algæ. — The algæ are a diverse collection of plants, containing some of the smallest and simplest as well as some of the largest plants in the world. The tiny one-celled plant which lives on the bark of trees is an example of the former; the giant kelp of the Pacific Ocean, which attains a length of over one thousand feet, of the latter. The body of the algæ is a thallus, which may be platelike, circular, ribbon-formed, threadlike, or filamentous. It may even be composed of a single cell. A large number of the algæ inhabit the water, fresh and salt. In color they vary from green through the shades of blue-green to yellow, brown, and red. The latter colors are best seen in the seaweeds, all of which, how-

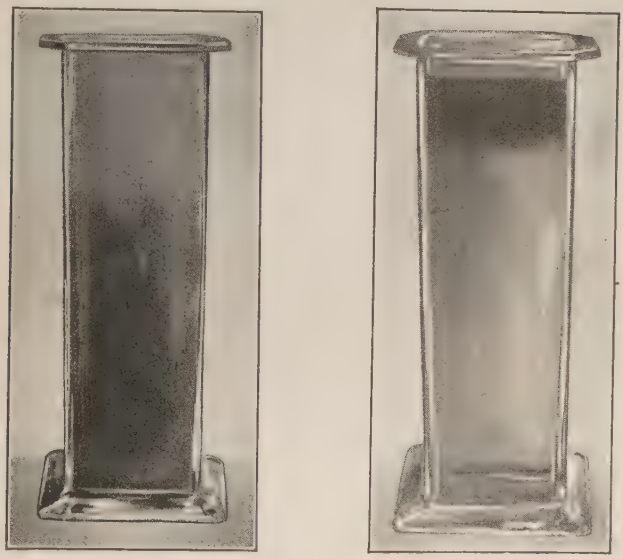
ever, contain chlorophyll. In the red and brown seaweeds the chlorophyll is concealed by other coloring material in the plant body. In the olive-brown fucus (the common rockweed) it is easy to prove the presence of chlorophyll by cutting open the bladders which are found in the plant body. The red seaweeds are among the most beautiful and delicate of all plants. They may be mounted under water upon cardboard and then studied after drying.

Rockweed, a brown alga, showing the distribution on rocks below high-water mark.

Green Algæ. — The plants known as the green algæ are of more interest to us because of their distribution in fresh water, and also because of their economic importance as a supply of oxygen for fish and other animals in the waters of our inland lakes and rivers. Our attention is called to them in an unpleasant way at times, when, after multiplying very rapidly during the hot summer, they die rapidly in the early fall and leave their remains in our water supply. Much of the unpleasant taste and odor of drinking water comes from this cause.

Pond Scum (*Spirogyra*). — This alga is well known to every boy or girl who has ever seen a small pond or sluggish stream. It grows as a slimy mass of green threads or filaments. Frequently it is so plentiful as almost to cover the surface of the water, buoyed

up by little bubbles of a gas which seems to arise from the body of the plant. If we collect some of this gas, we can easily prove that it is oxygen. The person who sees a pond with a covering of slimy

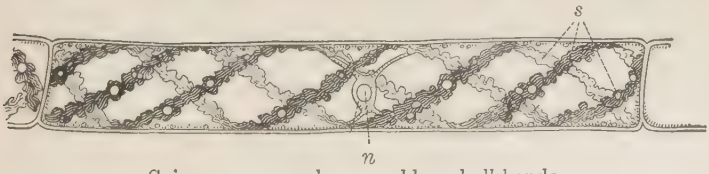


A *B*

A, jar of water containing pond scum; *B*, same jar after an hour in the sunlight; the pond scum has risen to the top of the jar, buoyed up by the oxygen formed within it.

pond scum, knowing this fact, should no longer feel that the pond is a menace to health, unless it is a place where mosquitoes live and breed.

Under the low power of the microscope, the body of a pond scum

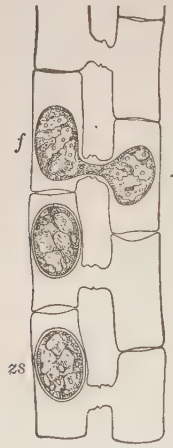


Spirogyra: *n*, nucleus; *s*, chlorophyll bands.

is seen to be a thread made up of elongated cylindrical cells, each of which contains a spirally wound band of chlorophyll within it.

Careful study shows the presence of strands held in the body of the cell by strands of protoplasm, the remainder of the space within the cell being occupied by the cell sap.

Pond scum may grow by a simple division of the cells in a filament. This method of *asexual* reproduction is the way growth takes place in the cells of the root, stem, or leaf of a flowering plant, but another method of reproduction is also seen in pond scum. The cells of two adjoining filaments may push out tubes which meet, thus connecting the cells with each other. Meantime the protoplasm of the cells thus joined condenses into two tiny spheres; the bands of chlorophyll are broken down, and ultimately the contents of one of the cells passes over the tube and mingles with the cell of the neighboring filament, with which it was previously connected by the tube formed from the cell walls. The result of this process of fusion is a thick-walled resting cell which we call a *zygospore*.



Conjugation of Spirogyra; *zs*, zygospore; *f*, fusion in progress.

Conjugation. — *The process in which two cells of equal size unite to form a single cell is called conjugation.* It is believed to be a *sexual* process which corresponds in a way to the fertilization in the higher plants.[1] This cell thus formed can withstand considerable extremes of heat and cold, and may be dried to such an extent that it is found in dust or in the air. Under favorable conditions, this spore will germinate and produce a filament.

Pleurococcus. — Many other forms of algæ are well known to us. One of the simplest is *pleurococcus*. This little plant consists of a single tiny cell, which by division may give rise to two, three, four, or even more cells which cling together in a mass. The green

Pleurococcus. *A*, single cell; *B*, colony of four cells formed from the original cell *A*.

[1] Material which shows conjugation is not always easy to obtain. Conjugation usually takes place most freely in the fall of the year. When material is obtained, it may be preserved in a 4 per cent solution of formol. Material killed in a 5 per cent solution of chromic acid and then preserved in 70 per cent alcohol or 4 per cent formol shows the details of cellular structure.

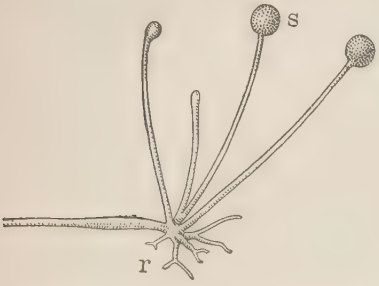
color on tree trunks, stone houses, etc., is due to millions of these little plants.

Diatoms. — These plants are found in vast numbers living on the mud or stones at the bottom of small streams. The plant body is inclosed in a cell wall composed largely of silica. Many of the diatoms are free-swimming. They compose a large percentage of the living organisms found near the ocean's surface.

Diatoms are found as fossils, and make up a large proportion of many rocks. The siliceous skeletons in such rocks are of commercial importance, the rock forming a basis for polishing powders.

Various forms of Diatoms.

Fungi, Parasites, and Saprophytes. — The thallus plants may be grouped in two great divisions: the *Algæ, water-loving thallophytes containing chlorophyll, and the Fungi, thallus plants which do not contain chlorophyll.* As a direct result of the lack of chlorophyll in the cells, the fungi are unable to make their own food. They must obtain food from other plants or animals. *Some take up their abode upon living plants or animals (in which case they are called parasites); others obtain their food from some dead organic matter. The latter are called saprophytes.* The above facts make the group of the fungi of immense economic importance to man.



Bread mold: *r*, rhizoids; *s*, sporangium.

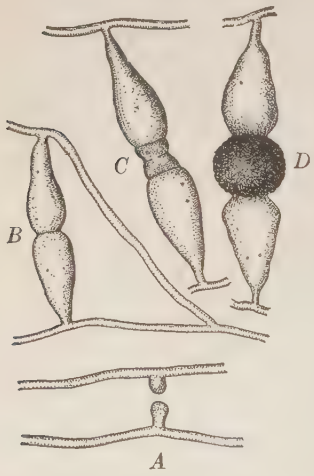
Mold (*Rhizopus nigricans*).— One of the most common of all our fungi is the black mold which appears growing upon bread, cake, and other organic substances under certain conditions of temperature and moisture.

The tangled mass of threads which cover the bread is called the *mycelium*, each thread being called a *hypha*. Many of the hyphæ are prolonged into tiny upright threads, bearing at the top a little ball. With the low power of the microscope each of these structures is seen to contain many tiny bodies called *spores*. These

spores have been formed by the division of the protoplasm making up the ball or *sporangium* into many separate bodies.

This method of the production of spores is evidently *asexual.* These spores, if grown under favorable conditions, will produce more mycelia, which in turn bear sporangia. It has been found, however, that at some time during the life of the mold another method of reproduction is likely to occur.

Formation of Zygospores. — Two hyphæ which are close-lying put out threads which communicate. The end of each of the threads cuts off a cell, and the two cells, each from a different hypha, flow together and mingle. In this condition they remain as a single resting cell. This cell, which puts a heavy wall around itself, is a *zygospore.* Here again we have a process of conjugation similar to that we observed in the pond scum. The ultimate result of the conjugation of the two cells is that a new plant grows from the zygospore after a period of rest. During the resting stage the spore may undergo very unfavorable conditions, even to extreme dryness, heat, or cold. The use of the zygospore to the plant is evidently to continue the species during an unfavorable time in the life history of the plant. The process of conjugation is probably a sexual process, as we have called it in pond scum.



Conjugation of black mold: *A*, *B*, *C*, *D*, successive stages in the formation of the zygospore.

Physiology of the Growth of Mold. — Mold, in order to grow rapidly, evidently needs oxygen, moisture, and heat. It obtains its food from the material on which it lives. This it is able to do by means of digestive ferments which are given out by the rhizoids or rootlike parts of the hyphæ, by means of which the mold clings to the bread. These ferments change the starch of

[1] It seems to have been proved recently that zygospores are formed by the union of two cells, from different filaments, one of which has male, the other female, characters.

the bread to sugar and the proteid to a soluble form which will pass by osmosis into the hyphæ. Thus the plant is enabled to absorb the material. These foods are then used to supply energy and make protoplasm. This seems to be the usual method by which saprophytes assimilate the materials on which they live.

Other Saprophytic Fungi. — The mushroom resembles a tiny umbrella. The upper part is known to botanists as the cap, the cap is held up by a stalk or stipe. The under surface of the cap discloses a number of structures which radiate out from the central stipe to the edge of the cap. These are the gills. If you place the cap of a mushroom gills downward on the surface of a piece of white paper, being careful not to disturb for at least twelve hours, it will be found that when the cap is removed a print of the shape and size of the gills remains on the paper. This is a spore print. It has been caused by the spores of the plant, which have fallen from the place where they were formed between the gills to the surface of the paper.

Mushrooms; the younger specimen, at the right, shows the mycelium. Photographed by Overton.

Mycelium. — The mushroom is, then, the spore-bearing part of the plant. Where is the plant body? This question is answered if we dig up a little of the earth surrounding a mushroom. In the rich black soil is seen a mass of little whitish threads. These threads form the mycelium of the fungus. The hyphæ of this part of the plant body take food from the organic matter in the soil and digest it in the same manner as did the hyphæ of black mold. The mushroom is a saprophyte. No sexual stage has yet been discovered.

Food Value of Mushrooms. — The food value of the edible mushroom has been much overestimated. Recent experiments seem to show that, although they have a slight food value, they are far from taking the place of nitrogenous foods, as was formerly believed by scientists.

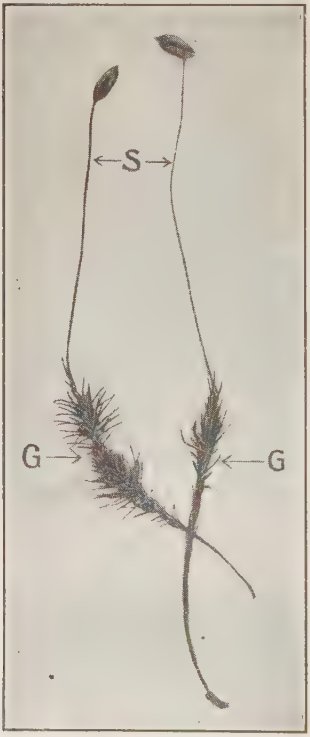
Other Fungi. — Many other plants, both useful and harmful to man, belong in this group; among them are the yeasts, the various parasitic

rusts and smuts, causing plant diseases, and, most important of all, the bacteria. We shall consider several of these plants later in their direct relation to the human race.

Mosses

Mosses are mostly shade-loving and moisture-loving plants. They form velvety carpets in many of our forests, but they often show their preference for moist localities by covering the wooded shores of lakes and swamps.

Pigeon-wheat Moss. — One of the mosses frequently seen and easily recognized is the so-called pigeon-wheat moss (*Polytrichum commune*). Unlike some mosses, it often inhabits dry localities. It may be found on some dry hillock close to the edge of the woods, where it forms a reddish brown carpet. This red color is due largely to the presence of a great number of little upright stalks, bearing at the summit tiny capsules, which seem to grow up from the leafy moss plant. The resemblance of a large number of these stalks and capsules to a mimic field of grain has given the name pigeon-wheat moss to this form.



Two moss plants, showing the gametophyte (*G*) and the sporophyte (*S*).

Forms of Plants. — Three kinds of moss plants appear to be present: leafy plants, others bearing a stalk and capsule, and still others which terminate at the end in a little rosette of leaves, inclosing what appears to be a tiny flower.

Leafy Moss Plant. — A leafy moss plant has rhizoids or hairlike roots, an upright stem, and green leaves. In the plants which have a stalk and capsule, the stalk grows directly from the end of the leafy plant. This capsule is provided with an outer cap which seems to have somewhat the structure of a thatched roof. Under the cap is found a lid, or cover, to the capsule. If this cover is removed and the capsule turned upside down, the dust that escapes will be found to be made up of a great number of spores.

Sporophyte. — The capsule is the spore-producing part (*sporangium*) of the moss plant. *The stalk and capsule together form the sporophyte or spore-producing generation of the moss.*

If we were to plant the spores of the moss in damp sand, taking care to keep the sand moist and warm, we might get them to grow. The spore germinates into a threadlike structure, very tiny, and not at all like the adult moss plant. This thread is called a *protonema.*

Adult Moss Plants. — The protonema soon develops rhizoids; tiny buds appear which in time form the adult moss plant. These adult plants may grow only leaves, and become what are known as sterile plants; or they may develop into a plant that bears at the summit the little rosette of leaves previously referred to. Within the rosette lie a number of tiny organs which hold large numbers of sperm cells. Other moss plants not so tall as the sperm-producing plants bear at the summit of the stem a tuft of leaves which hide a number of small flask-shaped structures, each of which contains a single egg cell. *These plants form the sexual generation of the moss. This stage of the plant is called the gametophyte, because it produces the gametes or sexual cells, — eggs and sperms.* After a sperm cell has been transferred (usually by means of a drop of dew) to the egg cell, a fusion of the two cells takes place. This, we remember, is the process of *fertilization.* In the mosses the fertilization of the egg cell results in the growth of that part of the plant which forms and bears the *asexual* spores.

Alternation of Generations. — In the mosses we have what is known as an *alternation of generations.* The leafy moss, bearing among its leaves the organs producing sperms and eggs, *antheridia* and *archegonia,* gives place to a stalk and capsule bearing the *asexual* spores. This spore-bearing portion of the plant does not appear until after fertilization; then it grows directly out of that part of the plant which produces the egg cell. In fact, if we make a microscopic examination of the egg-producing structure (the *archegonium*) directly after fertilization, we find that the sporophyte is a direct outgrowth from the fertilized egg cell. Thus the sexual stage alternates with the asexual stage in the life of the plant.

Sporophyte a Parasite. — One interesting fact comes out in connection with this growth of the sporophyte. It has no green leaves and must therefore obtain all its nourishment from the leafy moss plant, or gametophyte. The spore-bearing part of the plant is thus actually a parasite upon the gametophyte.

Ferns and their Allies

The Ferns and their Allies. — The fern plants include the true ferns, the horsetails or scouring rushes, and the club mosses. The true ferns are moisture-loving and shade-loving plants; they play an important part in the vegetation of the tropical forests. Many forms are found in the temperate regions; we even have some common ferns that remain green all winter. Fossil ferns have been found in Greenland, thus showing that at one time the climate at the north was milder than it now is.

A common fern is the polypody (*Polypodium vulgare*), the habitat of which is damp woods and rocky glens. These ferns are hard to procure entire, as they have an underground stem, from which at intervals the leaves or *fronds* arise. The leaflets or *pinnæ* at certain seasons show a series of little brown dots on the under surface. These structures, called collectively the *sori* (singular *sorus*), are made up of a number of tiny spore cases. These spore cases, or *sporangia*, hold the asexual spores. These spores under favorable conditions of heat and moisture may germinate to form a tiny thread of cells which soon develops into a flat, heart-shaped body not much bigger than a pinhead, called a *prothallus*.

Rock fern, polypody. Notice the underground stem giving off roots (*R*) from its under surface, and leaves (*C*) from the upper surface. The compound leaf or frond may bear sori (*S*) on the underside of the leaflets.

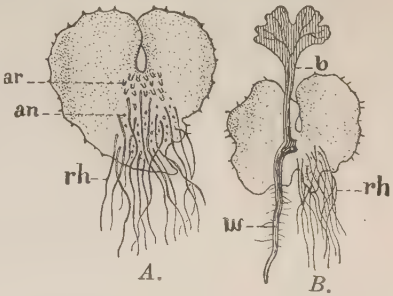
Prothallus. — The prothallus clings to the surface of the ground by means of its rhizoids. A careful examination of the prothallus with a compound microscope reveals the fact that scattered among the rhizoids are some tiny rounded elevations; immediately above the rhizoids and between them and the little groove (see Figure) in the prothallus are other structures; both the above structures are too minute to find with the naked eye.

Archegonia. — The last named are *archegonia;* they are found to be very tiny flask-shaped organs almost embedded in the surface of the prothallus. Each archegonium contains a single large egg cell.

A sporangium.

Antheridia. — The other structures found among the rhizoids are the *antheridia*. Each antheridium contains a large number of very minute objects which are able to move about in water by means of lashlike threads of protoplasm. Each of these motile cells is called an *antherozoid;* they have, in fact, the same function as the *sperm* cells of the flowering plants. Because this part of the plant holds the egg cells and sperm cells, we recognize it as the *sexual* generation of the fern.

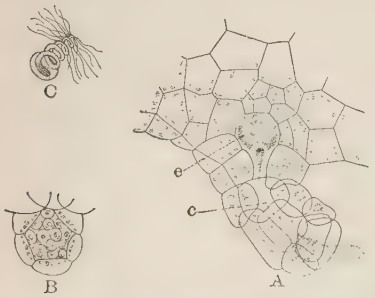
Fertilization. — The sperm cells swim to the egg cells in water (rain or dew), being attracted to the mouth of the flask-shaped archegonium by an acid secretion which is poured out by the cells forming the neck of the flask. Fertilization is essentially the same process that has been described for the flowering plants, the sperm cell uniting with the egg cell to form a single cell, the fertilized egg.



Prothalium of a common fern (*aspidium*): *A*, under surface, showing rhizoids, *rh*, antheridia, *an*, and archegonia, *ar*; *B*, under surface of an older gametophyte, showing rhizoids, *rh*, and young sporophyte, with root, *w*, and leaf, *b*. (From Coulter, *Plant Structures*.)

Sporophyte and Gametophyte. — The direct result of fertilization is the growth of the egg cell by repeated division to form a little fern plant. Later the young plant strikes root, the prothallus dies away, and we have a fern plant which will later in the season produce asexual spores. The leafy fern plant, because it produces asexual spores, is called the *sporophyte*. The prothallus, which forms the eggs and sperms, both of which are known as *gametes*, or sex cells, is called the *gametophyte*.

Alternation of Generations. — The fern plant like the moss also passes through two entirely different stages, or generations. The spore germinates to form a gametophyte, or sexual generation. This sexual generation in turn produces an asexual generation, or sporophyte. *The alternation, in the life history of a plant or animal, of a sexual stage with an asexual stage is called an alternation of generations.*



A, the archegonium with egg (*e*) and canal (*c*); *B*, antheridium; *C*, antherozoid, very highly magnified. — Strasburger.

General Characters of the Fern-like Plants. — These plants pass through an alternation of generations; they have a distinct root, stem, and leaves; and the stem possesses conducting tubes or fibro-vascular bundles; these are the distinguishing marks of the ferns and their allies. Fern plants show a great diversity in form and size. They vary from the great tree ferns of the tropics, some of which are thirty to forty feet in height, to tiny forms of almost microscopic size. The leaves of the ferns are among the most complex in form of any that we know.

The Horsetails. — These comprise a small group of plants, recognized by their erect habit of growth, the leaves coming out in whorls on the stem. In most forms the stem contains considerable silica. This gave to the plant its former useful place in the household and its name of the scouring rush. If you burn one of these plants very carefully on a tin plate over a very hot fire, the delicate skeleton of silica may be seen. The horsetails, or Equisetums, were once a very important part of the earth's vegetation. Before the coal fields were formed, the ancestors of these plants flourished as trees. A large amount of the coal of this country is undoubtedly formed from the trunks of the Equisetums of the Carboniferous age. At present they are represented by a very few species, none of which are over four or five feet in height.

Club Mosses. — Another relative of the fern is the club moss (*lycopodium*). It is familiar to us as a Christmas decoration under the name of ground pine. It is chiefly of interest now as the representative of another group of plants that flourished during the Carboniferous age.

Economic Value of Ferns. — It may be said that the ferns as a group have formed a large part of the enormous deposits of almost pure carbon that we call coal, from which we now derive the energy to run our many engines.

Sexual Reproduction in Flowering Plants. — Flowering plants reproduce their kind by the formation of seeds. As we know, the flower produces in the ovary structures which are known as *ovules*. In the interior of the ovule is found a clear protoplasmic area which is called the *embyro sac*. In this area is a cell (the egg cell) which is destined to form the future plant. In the pollen grain is found another cell, the *sperm*. This cell, after the germination of the pollen grain on the stigmatic surface of the flower, enters the ovule in the pollen tube and unites with the egg cell. The fertilized egg grows into the young plant within the seed, known as the embryo (see page 37).

This method of reproduction, called sexual reproduction, is found in the *spermatophytes*, that is, all seed-producing plants.

Botanists have shown that in the spermatophytes there exists an alternation of generations as in the mosses and ferns. The pollen grain is believed to contain the male gametophyte, while within the embryo sac is found the female gametophyte. Most of the life of the flowering plant is thus seen to be passed in the asexual or sporophyte stage. Thus we see that all plants — and all animals as well — form the cells which compose their bodies by either

sexual or asexual growth, and the stage of asexual growth is usually separated from the period of sexual growth.

Systematic Botany. — The plant world is divided into many tribes or groups. And not only are plants placed in large groups which have some very conspicuous characters in common, but smaller groupings can be made in which perhaps only a few plants having common characters may be placed. If we plant a number of peas so that they will all germinate under the same conditions of soil, temperature, and sunlight, the seedlings that develop will each differ one from another in a slight degree. But in a general way they will have many characters in common, as the shape of the leaves, the possession of tendrils, form of the flower and fruit. *The smallest group of plants or animals having certain characters in common that make them different from all other plants or animals is called a species.* Individuals of such species differ slightly; for no two individuals are exactly alike.

Species are grouped together in a larger group called a genus. For example, many kinds of peas — the garden peas, the wild beach peas, the sweet peas, and many others — are all grouped in one genus (called *Lathyrus*, or vetchling) because they have certain structural characteristics in common.

Plant and animal genera are brought together in still larger groups, the classification based on general likenesses in structure. Such groups are called, as they become successively larger, Family, Order, and Class. Thus the whole plant and animal kingdom is grouped into divisions, the smallest of which contains individuals very much alike; and the largest of which contains very many groups of individuals, the groups having some characters in common. This is called a system of classification.

Classification of the Plant Kingdom. — The entire plant kingdom has been grouped as follows by botanists: —

1. *Spermatophytes.* { *Angiosperms*, true flowering plants. / *Gymnosperms*, the pines and their allies.
2. *Pteridophytes.* The fern plants and their allies.
3. *Bryophytes.* Moss plants and their allies.
4. *Thallophytes.* The Thallophytes form two groups: the Algæ and the Fungi.

The extent of the plant kingdom can only be hinted at, because

each year new species are added to the lists There are about 110,000 species of flowering plants and nearly as many flowerless plants. The latter consist of over 3500 species of fernlike plants, some 16,500 species of mosses, over 5600 lichens (plants consisting of a partnership between algæ and fungi), approximately 55,000 species of fungi, and about 16,000 species of algæ.

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XII HOW PLANTS ARE MODIFIED BY THEIR SURROUNDINGS

Problem XXI. *How plants are modified by their surroundings.* (*Optional*). (*Laboratory Manual, Prob. XXI.*)

(*a*) *Hydrophytic society.*
(*b*) *Xerophytic society.*
(*c*) *Mesophytic society.*
(*d*) *Plant societies.*
(*e*) *Plant zonation.*

The Way in which Plants are Modified by their Surroundings. — As we have found in our experiments, young plants, and indeed any living plants, are delicate organisms, which are affected profoundly by the action of forces outside themselves. The presence or absence of moisture starts or prevents growth in seeds or young plants; absence of light changes the form and color of green plants; a certain temperature, which varies for different plants, seems to influence plants in a healthy growth. Pea seedlings may grow for a time in sawdust, but we know that they will be much healthier and will live longer if allowed to germinate in soil under natural conditions. We are forced to the conclusion that differences in the form and habits of plants are caused by the action of their surroundings upon them. The plants which have become in various ways fitted

Pond lilies, plants with floating leaves. Photograph by W. C. Barbour.

to live under certain conditions are said to be *adapted* to live under such conditions. Such plants as are best fitted to live under certain conditions are the ones which will survive.

Water Supply. — Water supply is one of the important factors in causing changes in structure of plants. Plants which live entirely in the water, as do many of the algæ, have slender parts, stemlike, and yet serving the place of a leaf. The interior of such a plant is made up of spongy tissues which allow the air dissolved in the water in which they live to reach all parts of the plant. If the plant has floating leaves, as in the pond lily, the stomata are all in the upper side of the leaf.

A water plant, showing the finely divided leaflike parts.

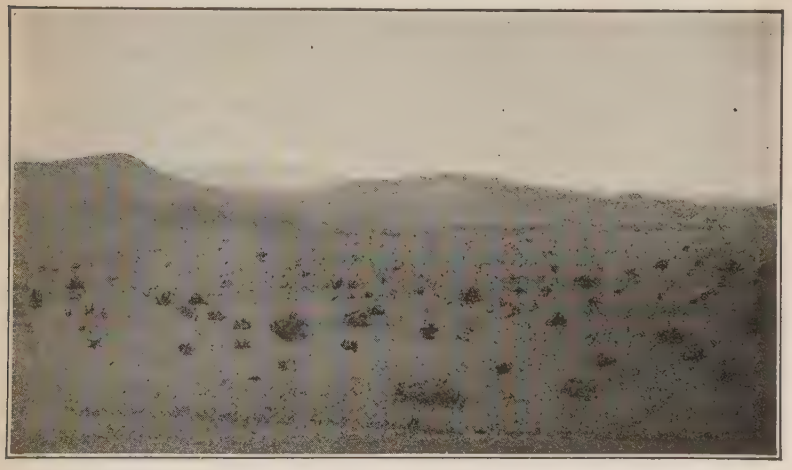
Plants living in water have not only loose and spongy tissues, but many large intercellular spaces are found in stems or leaves. In one pond lily (*Nelumbo lutea*) these spaces in the leaf communicate with large spaces in the veins of the leaf, and these in turn with spaces in the petiole, stem, and root, so that all parts of the plants are in communication with the air above. The roots of a plant living wholly in water are not needed for support, hence they are often short and stumpy. They do not need to be modified to absorb water; consequently the absorbing surface lacks root hairs. The whole plant, when under water, is usually modified to take water and material used in food-making from its immediate environment.

Hydrophytes. — If water is present in such quantity as to saturate the soil in which the plant lives, the conditions of its environment are said to be *hydrophytic*, and such plant is said to be a *hydrophyte*.

Xerophytes. — If we examine plants growing in dry or desert conditions, as cactus, sagebrush, aloe, etc., we find that the leaf surface is invariably reduced. Leaves are reduced to spines in the cactus. Some plants, such as the three-angled spurge, which bear leaves in a condition of moderate water supply, take on the

appearance of a cactus under desert conditions. Thus they lose their evaporating leaf surface by having the leaves changed into spines.

The stem may be thickened so as to store water; a covering of hairs or some other material may be present and lessen loss of



Xerophytic conditions. A typical desert.

moisture by evaporation. The conditions of extreme dryness under which such plants live is called *xerophytic*, and such plants are known as *xerophytes*. Examples of xerophytes are the cacti, yuccas, agaves, etc.

Halophytes. — If the water or saturated soil in which the plant lives contains salts, such as sea salt or the alkali salts of some of our Western lakes, then the conditions are said to be *halophytic*, and a plant living under such conditions is known as a *halophyte*.

Halophytes show many characteristics which xerophytes show, spines or hairs, thick epidermis, fleshy leaves, all being characters which show that the water supply of the plant is limited. The *density* of the salt water in the soil makes it difficult for the plant to absorb water; hence these characters are developed.

Mesophytes. — Most plants in the Temperate Zone occupy a place midway between the xerophytes on one hand and hydrophytes on the other. They are plants which require a moderate

amount of water in the soil and air surrounding them. Such are most of our forest and fruit trees, and most of our garden vegetables. Conditions of moderate moisture are called *mesophytic;* the plants living thus are known as *mesophytes.*

It may easily be seen that plants which are mesophytes at one time may under some conditions of weather be forced to undergo xerophytic or hydrophytic conditions. An oak tree may receive no water through the roots during the winter because the surface

A mesophytic condition. A valley in central New York.

of the ground is frozen, thus preventing water from finding its way below the surface; on the other hand, during excessive rains in the spring it might exist *for a time* under almost hydrophytic conditions. But many trees are annually killed in districts where lumbering is going on through the damming of streams and formation of artificial ponds, which increase the water supply of the trees near by and soon kill them.

Other Factors. — It is a matter of common knowledge that plants in different regions of the earth differ greatly from one another in shape, size, and general appearance. If we study the causes for

these changes, it becomes evident that the very same factor, water supply, which governs hydrophytic, xerophytic, and mesophytic conditions, determines, at least in part, the habits of the plants growing in a given region — be it in the tropics or arctic regions. But in addition to water supply, the factors of temperature, light, soil, wind, etc., all play important parts in determining the form and structure of a plant.

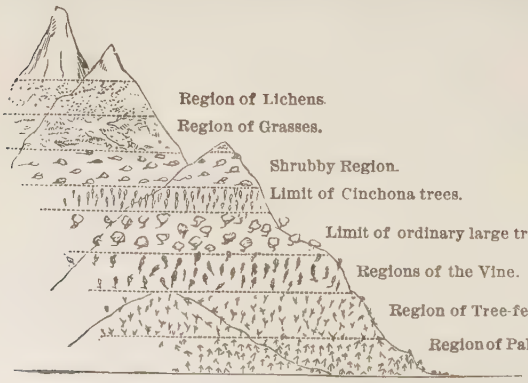
The effect of wind upon trees in an exposed location. Photograph by W. C. Barbour.

Cold Regions. — Here plants, which in lowland regions of greater warmth and moisture have a tall form and luxuriant foliage, are stunted and dwarfed; the leaves are smaller and tend to gather in rosettes, or are otherwise closely placed for warmth and protection. As we climb a mountain we find that the average size of plants decreases as we approach the line of perpetual snow. The largest trees occur at the base of the mountains; the same species of trees near the summit appear as mere shrubs. Continued cold and high winds are evidently the factors which most influence the slow growth and the size and shape of plants near the mountain tops. Cold,

little light during the short days of the long winter, and a slight amount of moisture all act upon the vegetation of the arctic region, tending toward very slow growth and dwarfed and stunted form.

Polar limit of trees, northern Russia. All these trees are full grown, and most of them are almost one hundred years old.

Vegetation of the Tropics. — A rank and luxuriant growth is found in tropical countries with a uniformly high temperature and large rainfall. In general it may be estimated that the rainfall in such countries is at least twice as great as that of New York state, and in many cases three to four times as great. An abundant water supply, together



Plant regions in a tropical mountain. Explain the diagram.

with an average temperature of over 80° Fahrenheit, causes extremely rapid growth. One of the bamboo family, the growth of which was measured daily, was found to increase in length on the average nearly three inches in the daytime and over five inches during each night. The moisture present in the atmosphere allows the growth of many air plants (*epiphytes*), which take the moisture directly from the air by means of aërial roots.

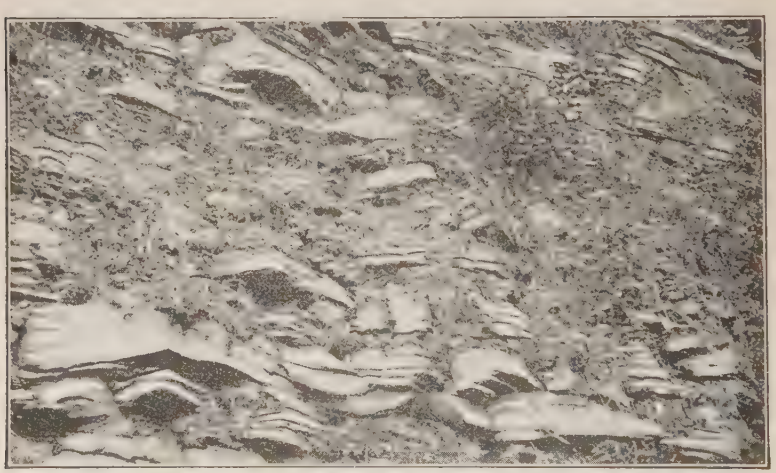
Conditions in a moist, semitropical forest. The so-called "Florida moss" is a flowering plant. Notice the resurrection ferns on the tree trunk.

The absence of cold weather in tropical countries allows trees to mature without a thick coating of bark or corky material, plants all having a green and fresh appearance. Monocotyledonous plants prevail. Ferns of all varieties, especially the largest tree ferns, are abundant.

Plant Life in the Temperate Zones. — In the state of New York, conditions are those of a typical temperate flora. Extremes of cold and heat are found, the temperature ranging from 30° Fahrenheit below zero in the winter to 100° or over in the summer. Conditions of moisture show an average rainfall of from 24 inches to 52

inches. Conditions of moisture in the country cause great differences in the plant covering.

In the eastern part of the United States the rainfall is sufficient to give foothold to great forests, which aid in keeping the water in the soil. In the Middle West the rainfall is less, the prairies are covered with grasses and other plants which have become adapted to withstand dryness. In the desert region of the Southwest we find true xerophytes, cacti, switch plants, yuccas, and others, all



A rock society. Photograph by W. C. Barbour.

plants which are adapted to withstand almost total absence of moisture for long periods. In the Temperate Zone the water supply is the primary factor which determines the form of plant growth.

Plant Formations and Societies.[1] — All of the factors alluded to act upon the plants we find living together in a forest, a sunny

[1] *Plant Societies. Field Work.* — Any boy or girl who has access to a vacant lot or city park can easily see that plants group themselves into societies. Certain plants live together because they are adapted to meet certain conditions. Societies of plants exist along the dusty edge of the roadside, under the trees of the forest, along the edge of the brook, in a swamp or a pond. It should be the aim of the field trips to learn the names of plants which thus associate themselves and the conditions under which they live, and especially their adaptations to the given conditions. Suggestions for such excursions are found in Andrews, *Botany All the Year Round;* Lloyd and Bigelow, *The Teaching of Biology;* and Canong, *The Teaching Botanist.* A convenient form for an excursion is found in Hunter and Valentine, *Manual,* page 202. This trip may be taken in the early fall.

meadow, along a roadside, or at the edge of a pond. Any one familiar with the country knows instinctively that we find certain plants, and those plants *only*, living together under certain conditions. For example, the wild columbine, certain ferns, and mosses, and other shade, moisture, and rock-loving plants are found together on rocky, shaded hillsides. We should not think of looking for daisies and buttercups there any more than we should look for

Plant societies near a pond. Notice that the plant groups are arranged in zones with reference to the water supply, the true mesophytes being in the background.

the marsh marigold (*Caltha palustris*) or the pickerel weed (*Pontederia cordata*) in a dry and sunny field.

Plants associated under similar conditions, as those of a forest, meadow, or swamp, are said to make up a *formation*, and a plant formation is brought about by the conditions of its immediate surroundings, the habitat of its members. If we investigate a plant formation, we find it to be made up of certain dominant species of plants; that here and there definite communities exist, made up of groups of the same kind of plants. We can see that every one of these plant groups in the society evidently originally came from single individuals of species which thrive under the peculiar conditions of soil, water, light, etc., that we find in this spot. These

single plants have evidently given rise to the members of each little family group, and thus have populated the locality.

So we find among plants communal conditions similar to those among some animals. The many individuals of the community live under similar conditions; they need the same substances from the air, the water, the soil. They all need the light; they use the same food. Therefore there must be competition among them, especially between those near to each other. The plants which are strongest and best fitted to get what they need from their surroundings live; the weaker ones are crowded out and die.

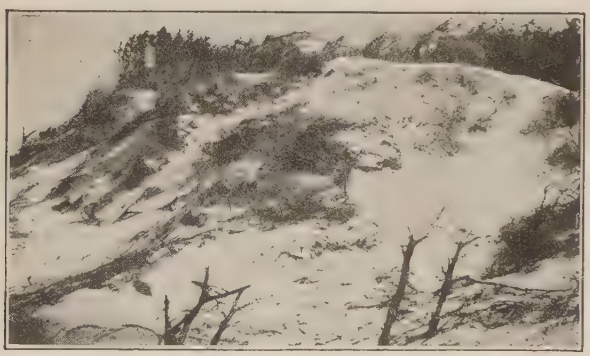
But their lives are not all competition. The dead plants and animals give nitrogenous material to the living ones, from which the latter make living matter; some bacteria provide certain of the green plants with nitrogen; many of the green plants make food for other plants lacking chlorophyll, while some algæ and fungi actually live together in such a way as to be of mutual benefit to each other. The larger plants may shelter the smaller ones, protecting them from wind and storm, while the trees hold the moisture in the ground, giving it off slowly to other plants. Animals scatter and plant the seeds far and wide, and man may even plant entire colonies in new localities.

A community of trilliums. Photograph by W. C. Barbour.

How Plants invade New Areas. — New areas are tenanted by plants in a similar manner. After the burning over of a forest, we find a new generation of plants springing up, often quite unlike the former occupants of the soil. First come the fireweed and other light-loving weeds, planted by means of their wind-blown seeds. With these are found patches of berries, the seeds of which were brought by birds or other animals. A little later, quick-growing trees having seeds easily carried for some distance by the wind,

like the aspen and wild cherry, which have the birds to help them out, invade the territory. Eventually we may have the area retenanted by its former inhabitants, especially if the destruction of the original forest was not complete.

In like manner, on the upper mountain meadow or by the sand dunes of the seashore, wherever plants place their outposts, the



A plant outpost. The struggle here is keen. The advancing sand has killed the trees in the foreground.

advance is made from some thickly inhabited area, and this advance is always aided or hindered by agencies outside of the plant — the wind, the soil, water, or by animals. Thus the seeds obtain a foothold in new territory, and thus new lands are captured, held, and lost again by the plant communities.

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Elementary

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Clements, *Plant Physiology and Ecology.* Henry Holt and Company.
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XIII. HOW PLANTS BENEFIT AND HARM MANKIND

Problem XXII. *The relations of fungi to man.* (*Laboratory Manual, Prob. XXII.*)

(*a*) *Yeast.*

(*b*) *Other fungi.*

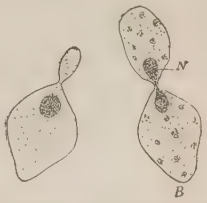
The Economic Value of Plants. — Besides the other relations existing between plants and animals, there is a relation between man and plants measurable in dollars and cents. Plants are of direct value or harm to man. We call this an economic relation. We have seen how they supply him with his cereals and flour, his fruits and garden vegetables, his nuts and spices, his beverages and the sugar to sweeten them, his medicines and his dyestuffs. They supply the material out of which many of his clothes are made, the thread with which they are sewed together, the paper which covers the package in which they are delivered, and the string with which the package is tied. The various uses of the forest have been mentioned before; the need of trees to protect the earth, their usefulness in the holding of the water supply, their direct economic importance for lumber and firewood. Many of us forget, too, that much of the energy released on this earth to man as heat, light, or motive power comes from the dead and compressed bodies of plants which thousands of years ago lived on the earth and now form coal. Plants are thus seen to be of immense direct economic importance to mankind.

The Harm Plants Do. — Unfortunately, plants do not all benefit mankind. We have seen the harm done by weeds, which scatter their numerous seeds far and wide or by other devices gain a foothold and preëmpt the territory which useful plants might occupy were they able to cope with their better-equipped adversaries. Plants with poisonous seeds and fruits are undoubtedly responsible for the death of many animals.

But by far the most harmful plants to mankind are the fungi.

Hundreds of millions' yearly damage may be laid directly to them. More than that, they are doubtless responsible for one half of the total human deaths. This is because of their parasitic habits.

Yeast. — Although as a group the fungi are harmful to man in the economic sense, nevertheless there are some fungi that stand in a decidedly helpful relationship to the human race. Chief of these are the yeast plants. Yeasts are found to exist in a wild state in very many parts of the world. They are found on the skins of fruits, in the soil of vineyards and orchards, in cider, beer, and other fluids, while they may exist in a dry state almost anywhere in the air around us. In a cultivated state we find them doing our work as the agents which cause the rising of bread, and the fermentation in beer and other alcoholic fluids.



A, yeast plant bud just forming; *B*, bud almost ready to leave parent cell. Note the nucleus (*N*) dividing into two parts. (After Sedgwick and Wilson.)

Size and Shape, Manner of Growth, etc. — The common compressed yeast cake contains millions of these tiny plants. In its simplest form a yeast plant is a single cell. If you shake up a bit of a compressed yeast cake in a mixture of sugar and water and then examine a drop of the milky fluid after it has stood overnight, it will be seen to contain vast numbers of yeast plants. The shape of such a plant is ovoid, each cell showing under the microscope the granular appearance of the protoplasm of which it is formed. Look for tiny clear areas in the cells; these are vacuoles, or spaces filled with fluid. The nucleus is hard to find in an unstained yeast cell; it can, however, be found in specimens which have been prepared by staining the previously killed cells with iron-hæmatoxylin.[1] Yeast cells reproduce very rapidly by a process of budding, a part of the parent cell forming one or more smaller daughter cells which eventually become free from the parent.

Most yeast plants seem to produce spores at some time during their existence. The spores are formed within a yeast cell, as many as four being produced within a single cell. These spores, under proper conditions, will germinate and give rise to new plants.

Conditions favorable to Growth of Yeast. - Under certain conditions yeast, when added to dough, will cause it to rise. We also know that yeast has something to do with the process we call fermentation. The following home experiment will throw some light on these points: —

Label three pint fruit jars A, B, and C. Add one fourth of a compressed yeast cake to two cups of water containing two tablespoonfuls of molasses or sugar. Stir the mixture well and divide it into three equal

[1] See Lee, *Vade Mecum*, or Sedgwick and Wilson, *General Biology*.

parts and pour them into the jars. Place covers on the jars. Put jar A in the ice box on the ice, and jar B over the kitchen stove or near a radiator; boil the jar C by immersing it in a dish of boiling water, and place it next to B. After forty-eight hours, look to see if any bubbles have made their appearance in any of the jars. If the experiment has been successful only jar B will show bubbles. After bubbles have begun to appear at the surface, the fluid in jar B will be found to have a sour taste and will smell unpleasantly. The gas which rises to the surface, if collected and tested, will be found to be carbon dioxide. The contents of jar B are said to have fermented. Evidently, the growth of yeast will take place only under conditions of moderate warmth and moisture.

Fermentation a Chemical Process. — In this process of growth the sugar of the solution in which they live is broken up by a digestive ferment or enzyme into carbon dioxide and alcohol. This may be expressed by the following chemical formula: $C_6H_{12}O_6 = 2(C_2H_6O) + 2(CO_2)$. This means that the sugar forms alcohol and carbon dioxide. This process, which we call fermentation, is of the greatest importance in the brewing industry.

Beer-Making. — Brewers' yeasts are cultivated with the greatest care; for the different flavors of beer seem to depend largely upon the condition of the yeast plants. Beer is made in the following manner: Sprouted barley, called malt, in which the starch of the grain has been changed to grape sugar by digestion, is killed by drying in a hot kiln. The malt is dissolved in water, and hops are added to give the mixture a bitter taste. Now comes the addition of the yeast plants, which multiply rapidly under the favorable conditions of food and heat. Fermentation results on a large scale from the breaking down of the grape sugar, the alcohol remaining in the fluid, and the carbon dioxide passing off into the air. The process is stopped at the right instant, and the beer is stored either in bottles or casks.

Bread-Making. — In bread-making the rapid growth of the yeast plants is facilitated by placing the pan containing the mixture in a warm place overnight. Fermentation results from the digestion of grape sugar by the yeasts, this grape sugar being part of the starch in the flour which is changed by the diastase present in the grain of wheat. The carbon dioxide remains in the dough as the bubbles so familiar to the bread-maker, the alcohol produced being evaporated during the process of baking.

Yeast Saprophytes. — The above paragraphs show yeast plants to be saprophytes. In order to grow, they must be supplied with food materials that will build up protoplasm as well as release energy. This food they obtain from the organic matter in the fluids in which they happen to be.

The Shelf Fungus; a Saprophyte. — A near relation to the mushroom is the bracket or shelf fungus. This fungus is familiar to any one who has been in a forest in this part of the country.

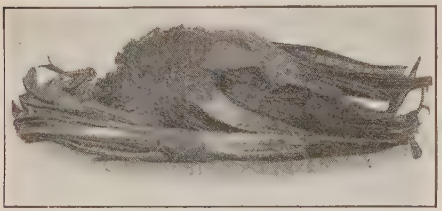
An examination of specimens shows that the shelf or bracket is in reality a spore case, which is usually provided with a very considerable number of holes, slits, or pores in which the spores are formed. The spores when ripe escape from the under surface of the spore-bearing body through the minute pores. The mycelium is within the tissue of the tree. Remove the bark from any tree infected with bracket fungus, and you will find the silvery threads of the mycelium sending their greedy hyphæ to all parts of the wood adjacent to the spot first attacked by the fungus. This fungus begins its life by the lodgment of a spore in some part of the tree which has become *diseased* or *broken*. Once established on its host, it spreads rapidly. There is no remedy except to kill the tree and burn it, so as to destroy the spores. Many fine trees, sound except for a slight bruise or other injury, are annually infected and eventually killed. In cities thousands of trees become infected through careless hitching of horses so that the horse may gnaw or crib on the tree, thus exposing a fresh surface on which spores may obtain lodgment and grow (see page 142).

Shelf or bracket fungi on dead tree trunk.

Suggestions for Field Work. — A field trip to a park or grove near home may show the great destruction of timber by this means. Count the number of perfect trees in a given area. Compare it with the number of trees attacked by the fungus. Does the fungus appear to be transmitted from one tree to another near at hand? In how many instances can you discover the point where the fungus first attacked the tree?

Parasitic Fungi. — Of even more importance are the fungi that attack a living host, true parasites. The most important of such

plants from an economic standpoint are the rusts, smuts, and mildews which prey upon grain, corn, and other cultivated plants. Some fungi are also parasitic upon fruit and shade trees. The chestnut canker, a fungus recently introduced on chestnuts planted near New York city, has within five years practically destroyed all the chestnut trees within a radius of twenty miles of the city, and is estimated to have done $10,000,000 damage already. Damage extending to hundreds of millions of dollars is annually done by the fungi.



Corn smut, a fungus parasitic on corn; the black mass consists almost entirely of ripe spores.

Wheat Rust. — Wheat rust is probably the most destructive parasitic fungus. For hundreds of years wheat rust has been the most dreaded of plant diseases, because it destroys the one harvest upon which the civilized world is most dependent. For a long time past the appearance of rust has been associated with the presence of barberry bushes in the neighborhood of the wheat fields. Although laws were enacted nearly two hundred years ago in New England to provide for the destruction of barberry bushes near infected wheat fields, nothing was actually known of the relation existing between the rust and the barberry until recently. It has now been proved beyond doubt that the wheat rust passes part of its life as a parasite on the barberry and from it gets to the wheat plant, where it undergoes a complicated life history. The wheat leaf, its nourishment and living matter used as food by the parasite, soon dies, and no grain is produced. Some wheat rusts do not have two hosts, living only on the wheat and wintering over by means of thick-walled spores which remain in the stubble or in the ground until the young wheat plants appear the following year.

Mildews. — Another group of fungi that are of considerable economic importance is made up of the sac fungi. Such fungi are commonly called mildews. Some of the most easily obtained specimens come from the lilac, rose, or willow. These fungi do not penetrate the host plant to any depth, but cover the leaves of the host with the whitish threads of the mycelium. Hence they may be killed by means of applications of some fungus-killing fluid, as Bordeaux mixture.[1] They obtain their food from the outer

[1] See Goff and Mayne, *First Principles of Agriculture*, page 59, for formula of Bordeaux mixture.

layer of cells in the leaf of the host. Among the useful plants preyed upon by this group of fungi are the plum, cherry, and peach trees. (The diseases known as black knot and peach curl are thus caused.) Other sac fungi are the morels and truffles, the downy mildews, blue and green molds, and many other forms. One important member of this group is the tiny parasite found on rye and other grains, which gives us the drug ergot.

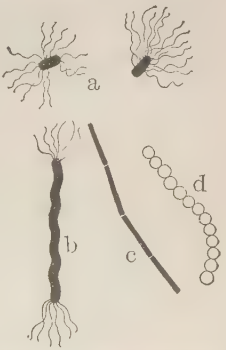
Problem XXIII. *A study of bacteria and of some of their relations to man. (Laboratory Manual, Prob. XXIII.)*

(*a*) *Conditions of growth.*

(*b*) *Some relations to man.*

(*c*) *Some methods of fighting harmful bacteria.*

Bacteria. — The bacteria are found in the earth, the water, and the air. "Anywhere but not everywhere," as one writer has put it. They swarm in stale milk, in impure water, in the living bodies of plants and animals, and in any decaying material. These tiny plants, "man's invisible friends and foes," are of such importance to mankind that thousands of scientists devote their whole lives to their study, and a science called *bacteriology* has been named after them.



Bacteria, highly magnified: *a*, the germ of typhoid fever, stained to show the cilia, little threads of living matter by means of which locomotion is accomplished; *b*, a spiral ciliated form; *c*, a rod-shaped form, in chains; *d*, a spherical form. — *a*, *b*, from Engler and Prantl.

Size and Form. — In size, bacteria are the most minute plants known. A bacterium of average size is about $\frac{1}{5000}$ of an inch in length, and perhaps $\frac{1}{25000}$ of an inch in diameter. Some species are much larger, others smaller. A common spherical form is $\frac{1}{5000}$ of an inch in diameter. It will mean more to us, perhaps, if we remember that several millions of bacteria of average size may be placed within the area formed in this letter *o*. Three well-defined forms of bacteria are recognized: a spherical form called a *coccus*, a rod-shaped bacterium, the *bacillus*, and a spiral form, the *spirillum*. Some bacteria are capable of movement when living in a fluid. Such

movement seems to be caused by tiny lashlike threads of protoplasm called *cilia*. The cilia project from the body, and by a rapid movement cause locomotion to take place. Bacteria reproduce with almost incredible rapidity. It is estimated that a single bacterium, by a process of division called *fission*, will give rise to over 16,700,000 others in twenty-four hours. Dr. Prudden has estimated that such a bacterium, if allowed to develop unchecked for five days, would fill all the oceans of this earth to a depth of one mile. Under unfavorable conditions they stop dividing and form spores, in which state they remain until conditions of temperature and moisture are such that growth may begin again.

Method of Study. — In order to get a number of bacteria of a given kind to study, it becomes necessary to grow them in what is known as a pure culture. This is done by first growing the bacteria in some medium such as beef broth, gelatin, or on potato.[1] The material used as a growth medium is at first sterilized by heating to such a temperature as to kill all life that might be there. If the material is exposed to the air of the schoolroom in a shallow dish (known as a Petri dish), or in a test tube in the case of beef broth, for say five minutes, and if then the dish or tube is covered and put away in a warm place for a day or two, little spots will appear on the surface of the gelatin or potato, or the beef broth will become cloudy.

A Petri dish culture of bacteria; the colonies of bacteria are the little spots of various size and color.

Pure Culture. — The spots are colonies composed of millions of bacteria. If now we wish to study one given form, it becomes necessary to isolate them from the others on the plate. This is done by the following process: A platinum needle is first passed through a flame to *sterilize* it; that is, to kill all living things that may be on the

[1] For directions for making a culture medium, see Peabody, *Manual of Physiology*. Culture tubes may be obtained, already prepared, from Parke, Davis, and Company.

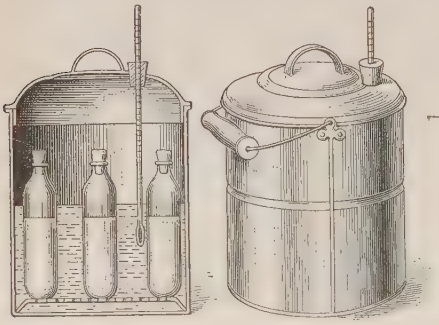
needle point. Then the needle, which cools very quickly, is dipped in a colony containing the bacteria we wish to study. This mass of bacteria is quickly transferred to another sterilized plate, and this plate is immediately covered to prevent any other forms of bacteria from entering. When we have succeeded in isolating a certain kind of bacteria in a given dish, we are said to have a pure culture.

Bacteria cause Decay. — Bacteria in several ways, either directly or indirectly, affect mankind. First of all, they cause decay. All organic matter, in whatever form, is sooner or later decomposed by the action of untold millions of bacteria which live in the air, water, and soil. To a considerable degree, then, these bacteria are useful in feeding upon the dead bodies of plants or animals, which otherwise would soon cover the surface of the earth to the exclusion of everything else. Bacteria may thus be scavengers. They oxidize organic materials, changing them to compounds of nitrogen that can be absorbed by plants and used in building protoplasm. Without bacteria and other fungi life on the earth would be impossible, for green plants would be unable to get the raw materials in forms that could be used in making food and new living matter. In this respect bacteria are of the greatest service to mankind.

When bacteria grow in sufficient numbers upon foods, meat, fish, or vegetables, they spoil them, and may form poisonous substances called *ptomaines*. Such substances are formed as waste products by the bacteria, and are given off into the material in which the bacteria are living. Thus we, upon eating the food containing these poisons, may become violently ill as the result of ptomaine poisoning. Fish and meats that have been kept for some time in cold storage are very easily spoiled, and should be avoided. Jars of canned goods that have "worked," that is in which yeasts or bacteria have caused fermentation and decay, are unfit for food.

Relation to Fermentation. — They may incidentally, as a result of this process of decay, aid in the process of fermentation. In making vinegar the yeasts first make alcohol (see p. 172), which the bacteria change to acetic acid. The lactic acid bacteria which sour milk, changing the milk sugar to an acid, grow very rapidly in a warm temperature; hence milk which is kept cool or which is pasteurized (that is, kept at a temperature of about 176°

Fahrenheit for five to twenty minutes for the purpose of killing the bacteria) will not sour readily, if kept in a cool place. Why? These same lactic acid bacteria may be useful when they sour the milk for the cheese-maker. Certain other bacteria give flavor to cheese and butter, while still others are used by the tanner.



A pasteurizing apparatus.

Nitrogen-fixing Bacteria. —Still other bacteria, as we have seen before, "change over" nitrogen in organic material in the soil and even the free nitrogen of the air so that it can be used by plants in the form of a compound of nitrogen. The bacteria living in tubercles on the roots of clover, beans, peas, etc., have the power of thus "fixing" the free nitrogen in the air found between particles of soil. This fact is made use of by farmers who rotate their crops, growing first a crop of clover or alfalfa, which produce the bacteria, then plowing these up and planting another crop, as wheat or corn, on the same area. The latter plants, making use of the nitrogen compounds there, produce a larger crop than when grown in ground containing less nitrogenous material.

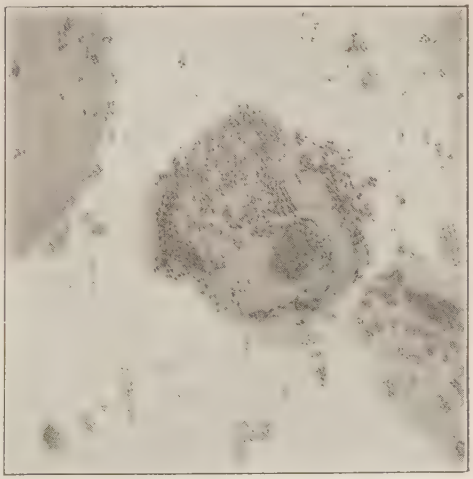
Nodules contain the nitrogen fixing bacteria on the roots of clover.

Bacteria cause Disease. —The most harmful bac-

teria are those which cause disease. This they do by becoming parasites in the human body. Millions upon millions of bacteria exist in the human body at all times — in the mouth, on the teeth, and especially in the lower part of the food tube. Some in the food tube are believed to be useful, others harmless; still others cause decay of the teeth, while a few kinds, if present there, may cause disease.

It is known that bacteria, like any other living things, feed and give off organic waste. This waste, called a *toxin*, is poison to the hosts on which the bacteria live, and it is usually the production of this toxin that causes the symptoms of disease. Some forms, however, break down tissues and plug up the small blood vessels, thus causing disease.

Diseases caused by Bacteria. — It is estimated that bacteria cause annually over 50 per cent of the deaths of the human race. As we will later see, a very large proportion of these diseases might be prevented if people were educated sufficiently to take the proper precautions to prevent their spread. These precautions might save the lives of some 3,000,000 of people yearly in Europe and America. Tuberculosis, typhoid fever, diphtheria, pneumonia, blood poisoning, syphilis, and a score of other germ diseases ought not to exist. A good deal more than half of the present misery of this world might be prevented and this earth made cleaner and better by the coöperation of the young people now growing up to be our future home-makers.

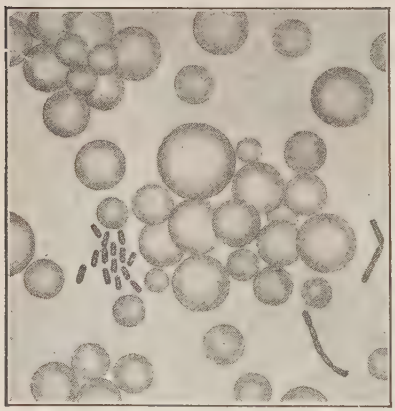


A single cell scraped from the roof of the mouth and highly magnified. The little dots are living bacteria, most of them comparatively harmless.

Germ or contagious diseases either enter the body by way

of the mouth, nose, or other body openings or through a break in the skin. They may be carried by means of air, food, or water, and are usually transmitted from the person having the disease either by personal contact, by handling articles used by them or by using foods which have received bacteria from their infected bodies. Thus with knowledge much contagious disease may be prevented.

Tuberculosis. — The one disease responsible for the greatest number of deaths — perhaps one seventh of the total on the globe — is tuberculosis. But this disease is slowly but surely being overcome. It is believed that within perhaps fifty years, with the aid of good laws and sanitary living, it will be almost extinct.

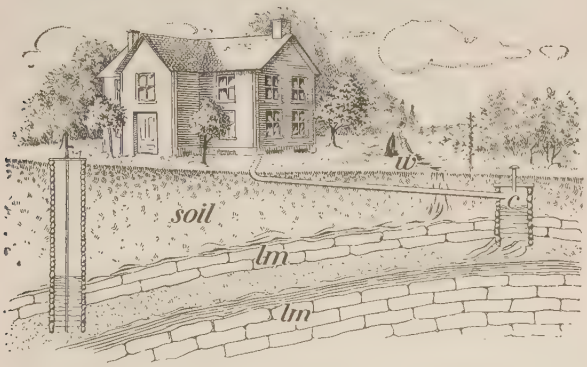


Microscopic appearance of ordinary milk showing fat globules and bacteria. The cluster of bacteria on left side are lactic-acid-forming germs. Tuberculosis germs are sometimes found in milk.

Tuberculosis is caused by the growth of a bacterium, called the *tubercle bacillus*, within the lungs or other tissues of the human body. Here it forms little tubers full of germs, which close up the delicate air passages in the lungs, and in other tissues give rise to hip-joint disease, scrofula, lupus, and other diseases, depending on the part of the body they attack. Tuberculosis may be contracted by taking the bacteria into the throat or lungs by eating meat or drinking milk from tubercular cattle. Especially is it communicated from a consumptive to a well person by kissing, drinking, or eating from the same cup or plate, using the same towels, or in any way coming in direct contact with the person having the germs in his body. Although there are always some of the germs in the air of an ordinary city street, and though we may take some of these germs into our bodies at any time, yet the bacteria seem able to gain a foothold only under certain conditions. It is only when the tissues are in a worn-out condition, when we are "run down," as we say, that the parasite may obtain a foothold in the lungs.

Even if the disease gets a foothold, it is quite possible to cure it if it is taken in time. The germ of tuberculosis is killed by exposure to bright sunlight and fresh air. Thus the course of the disease may be arrested, and a permanent cure brought about, by a life in the open air, the patient sleeping out of doors, taking plenty of nourishing food and very little exercise. See also Chapter XXIX.

Typhoid Fever. — One of the most common germ diseases in this country and Europe is typhoid fever. This is a disease which is conveyed by means of water and food, especially milk, oysters,



How sewage containing typhoid bacteria may get into drinking water: *c*, cesspool; *lm*, layer of rock; *w*, wash water.

and uncooked vegetables. Typhoid fever germs live in the intestine, from there they get into the blood and give off a poison which causes the fever characteristic of the disease. The germs multiply very rapidly in the intestine and are passed off from the body with the excreta from the food tube. If these germs get into the water supply of a town, an epidemic of typhoid will result. Among the recent epidemics caused by the use of water containing typhoid germs have been those in Butler, Pa., where 1364 persons were made ill; Ithaca, N.Y., with 1350 cases; and Watertown, N.Y., where over 5000 cases occurred. Another source of infection is milk. Frequently epidemics have occurred which were confined to users of milk from a certain dairy. Upon investigation it was found that a case of typhoid had occurred on the farm where the milk came from, that the germs had washed into the well, and that this

water was used to wash the milk cans. Once in the milk, the bacteria multiplied rapidly, so that the milkman gave out cultures of typhoid in his milk bottles. Proper safeguarding of our water and milk supply is necessary if we are to keep typhoid away.

Tetanus, or Blood Poisoning. — The bacterium causing blood poisoning is another toxin-forming germ. It lives in the earth and enters the body through cuts or bruises. It seems to thrive best in less oxygen than is found in the air. It is therefore important not to close up with court-plaster wounds in which such germs may have found lodgment. It, with typhoid, is responsible for four times as many deaths as bullets and shells in time of battle. The wonderfully small death rate of the Japanese army in their war with Russia was due to the fact that the Japanese soldiers always boiled their drinking water before using it, and their surgeons always dressed all wounds on the battlefield, using powerful antiseptics in order to kill any bacteria that might find lodgment in the exposed wounds.

Other Diseases. — Many other diseases have been traced to bacteria. Diphtheria is one of the best known. As it is a throat disease, it may easily be conveyed from one person to another by kissing, putting into the mouth objects which have come in contact with the mouth of the patient having diphtheria, or by food into which the germs have been carried. The disease syphilis probably causes more misery than any other germ disease. It causes hundreds of thousands of children to be born crippled or otherwise handicapped for life. Grippe, pneumonia, whooping cough, and colds are believed to be caused by bacteria. Other diseases, as malaria, yellow fever, sleeping sickness, and probably smallpox, scarlet fever, and measles, are due to the attack of one-celled animal parasites. Of these we shall learn later in the chapter on Protozoa.

Methods of fighting Germ Diseases. — As we have seen, diseases produced by bacteria may be caused by the bacteria being transferred from one person directly to another, or the disease may obtain a foothold in the body from food, water, by breathing in the germs in the air, or by taking them into the blood through a cut or a wound or a body opening.

It is evident that as individuals we may each do something to

prevent the spread of germ diseases, especially in our homes. We may keep our bodies, especially our hands and faces, clean. Sweeping and dusting may be done with damp cloths so as not to raise a dust; our milk and water, when from a suspicious supply, should be *sterilized*, — that is, the germs contained killed by boiling or pasteurizing for a few minutes. Wounds through which bacteria might obtain foothold in the body should be washed with some *antiseptic*, a substance like corrosive sublimate (1 part to 1000 water) or carbolic acid (1 part to 40 water), which kills the germs. In a later chapter we shall learn more of how we may coöperate with the authorities to combat disease and make our city or town a better place to live in.[1]

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[1] Teachers may take up parts or all of Chapter XXIX at this point. I have found it advisable to repeat much of the work on bacteria *after* the students have taken up the study of the human organism.

XIV. THE RELATIONS OF PLANTS TO ANIMALS

Problem XXIV. *The general biological relations existing between plants and animals.* (*Laboratory Manual, Prob. XXIV.*)

(*a*) *A balanced aquarium.*

(*b*) *Relations between green plants and animals.*

(*c*) *The nitrogen cycle.*

(*d*) *A hay infusion.*

Study of a Balanced Aquarium. — Perhaps the best way for us to understand the interrelation between plants and animals is to study an aquarium in which plants and animals live and in which a balance has been established between the plant life on one side and animal life on the other. Aquaria containing green pond weeds, either floating or rooted, a few snails, some tiny animals known as water fleas, and a fish or two will, if kept near a light window, show this relation.

We have seen that green plants under favorable conditions of sunlight, heat, moisture, and with a supply of raw food materials, give off oxygen as a by-product while manufacturing food in the green cells. We know the necessary raw materials for starch manufacture are carbon dioxide and water, while nitrogenous material is necessary for the making of proteids within the plant. In previous experiments we have proved that carbon dioxide is given off by any living thing when oxidation occurs in the body. The crawling snails and the swimming fish give off carbon dioxide, which is dissolved in the water; the plants themselves, night and day, oxidize food within their bodies, and so must pass off some carbon dioxide. The green plants in the daytime use up the carbon dioxide obtained from the various sources and, with the water taken in, manufacture starch. While this process is going on, oxygen is given off to the water of the aquarium, and this free oxygen is used by the animals.

But the plants are continually growing larger. The snails and fish, too, eat parts of the plants. Thus the plant life gives food

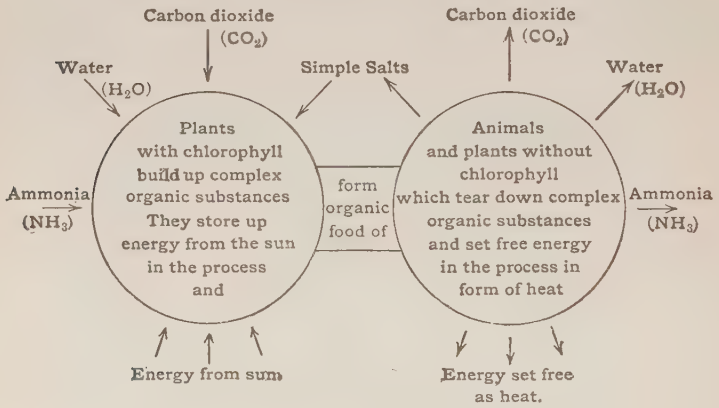
to at least part of the animal life within the aquarium. The animals give off certain nitrogenous wastes of which we shall learn more later. These materials, with other nitrogenous matter from the dead parts of the plants or animals, form the part of the raw material of the proteid food manufactured within the plant. The animals eat the plants and give off organic waste, from which the

A balanced aquarium.

plants make their food and living matter. The plants give off oxygen to the animals, and the animals give carbon dioxide to the plants. Thus a balance exists between the plants and animals in the aquarium.

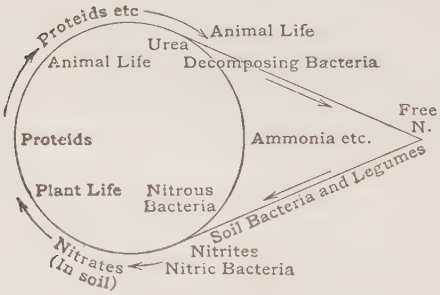
Relations between Green Plants and Animals. — What goes on in the aquarium is an example of the relation existing between all green plants and all animals. Everywhere in the world green plants are making food which becomes, sooner or later, the food of

animals. Man may not feed upon the leaves of plants, but he eats fruits and seeds in one form or another. Even if he does not feed directly upon plants, he eats the flesh of herbivorous animals,



The relations between green plants and animals.

which in turn feed directly upon plants. And so it is the world over; the plants are the food-makers and supply the animals. Green plants also give a very considerable amount of oxygen to the atmosphere every day, which the animals may make use of.

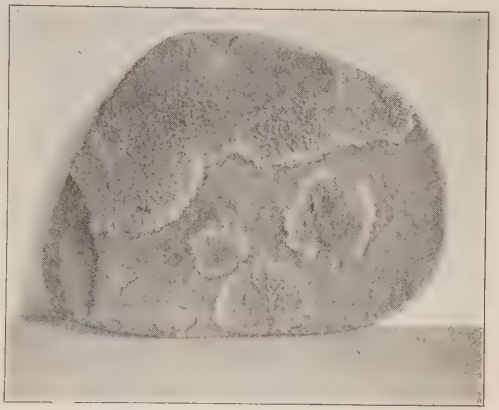


The nitrogen cycle.

The Nitrogen Cycle. — The animals in their turn supply much of the carbon dioxide that the plant uses in starch-making. They also supply most of the nitrogenous matter used by the plants, part being given the plants from the dead bodies of their own relatives and part being released through the agency of bacteria, which live upon the roots of certain plants. These bacteria are the only organisms that can take nitrogen from the air. Thus, in spite of all the nitrogen of the atmosphere, plants and animals are limited in the amount

available. And the available supply is used over and over again, perhaps in nitrogenous food by an animal, then it may be given off as organic waste, get into the soil, and be taken up by a plant through the roots. Eventually the nitrogen forms part of the food supply in the body of the plant, and then may become part of its living matter. When the plant dies, the nitrogen is returned to the soil. Thus the usable nitrogen is kept in circulation.

Symbiosis. — Plants and animals are seen in a general way to be of mutual advantage to each other. Some plants, called *lichens*, show this mutual partnership in the following interesting way. A lichen is composed of two kinds of plants, one at least of which may live alone, but which have formed a partnership for life, and have divided the duties of such life between them. In most lichens the alga, a green plant, forms starch and nourishes the fungus. The fungus, in turn, produces spores, by means of which new lichens are started in life. The body of the lichen is usually protected by the fungus, which is stronger in structure than the green part of the combination. *This process of living together for mutual advantage is called symbiosis.* Some animals thus combine with plants; for example, the tiny animal known as the hydra with certain of the one-celled algæ, and, if we accept the term in a wide sense, all green plants and animals live in this relation of mutual give and take. Animals also frequently live in this relation to each other, as the crab, which

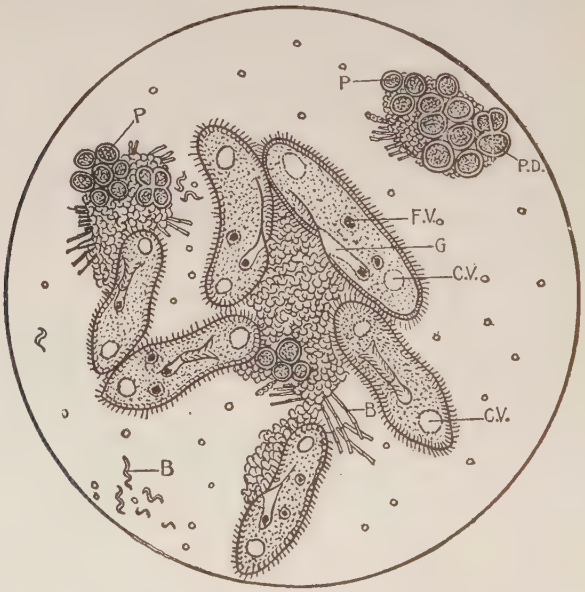


A lichen (*Physcia stellaris*). Photographed by W. C. Barbour.

Stages in the formation of the lichen thallus, showing the relation of the threadlike fungus to the green cells of the alga. (After Bornet.)

lives within the shell of the oyster; the sea anemones, which are carried around on the backs of some hermit crabs, aiding the crab in protecting it from its enemies, and being carried about by the crab to places where food is plentiful.

A Hay Infusion. — Still another example of the close relation between plants and animals may be seen in the study of a hay



Life in a late stage of a hay infusion. *B*, bacteria, swimming or forming masses of food upon which the one-celled animals, the paramoecia, are feeding; *G*, gullet; *F.V.*, food vacuole; *C.V.*, contractile vacuole; *P*, pleuococcus; *P.D.*, pleurococcus dividing.

infusion. If we place a wisp of hay or straw in a small glass jar nearly full of water, and leave it for a few days in a warm room, certain changes are seen to take place in the contents of the jar; the water after a little while gets cloudy and darker in color, and a scum appears on the surface. If some of this scum is examined under the compound microscope, it will be found to consist almost entirely of bacteria. These bacteria evidently aid in the decay which (as the unpleasant odor from the jar testifies) is taking place. As we have learned, bacteria flourish wherever the food supply is

abundant. The water within the jar has come to contain much of the food material which was once within the leaves of the grass, — organic nutrients, starch, sugar, and proteids, formed in the leaf by the action of the sun on the chlorophyll of the leaf, and now released into the water by the breaking down of the walls of the cells of the leaves. The bacteria themselves release this food from the hay by causing it to decay. After a few days small one-celled animals appear; these multiply with wonderful rapidity, so that in some cases the surface of the water seems to be almost white with active one-celled forms of life. If we ask ourselves where these animals come from, we are forced to the conclusion that they must have been in the water, in the air, or on the hay. Hay is dried grass, which may have been cut in a field near a pool containing these creatures. When these pools dried up, the wind may have scattered some of these little organisms in the dried mud or dust. Some may exist in a dormant state on the hay, the water serving to awaken them to active life. In the water, too, there may have been some living cells, plant and animal.

At first the multiplication of the tiny animals within the hay infusion is extremely rapid; there is food in abundance and near at hand. After a few days more, however, several kinds of one-celled animals may appear, some of which prey upon others. Consequently a struggle for life begins, which becomes more and more intense as the food from the hay is used up. Eventually the end comes for all the animals unless some green plants obtain a foothold within the jar. If such a thing happens, food will be manufactured within their bodies, a new food supply arises for the animals within the jar, and a balance of life results.

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XV. THE PROTOZOA

Problem XXV. *The study of a one-celled animal.* (*Laboratory Manual, Problem XXV.*)

(*a*) *In its relations to its surroundings.*

(*b*) *As a cell.* (*Optional.*)

(*c*) *In its relations to man.*

We have seen that perhaps the simplest plant would be exemplified by one of the tiny bacteria we have just read about. A typical one-celled plant, however, would contain green coloring matter or chlorophyll, and would have the power to manufacture its own food under conditions giving it a moderate temperature, a supply of water, oxygen, carbon dioxide, and sunlight. Such a simple plant is the pleurococcus, the "green slime" seen on the shady sides of trees, stones, or city houses. This plant would meet one definition of a cell, as it is a minute mass of protoplasm containing a nucleus. It is surrounded by a wall[1] of a woody material which covers a delicate membrane formed by the activity of the living matter within the cell. It also contains granules of protoplasm colored green, called chloroplasts. Of their part in the manufacture of organic food we have already learned. Such is a simple plant cell. Let us now examine a simple animal cell in order to compare it with that of a plant.

The Paramœcium. — The one-celled animal most frequently found in hay infusions is the paramœcium, or slipper animalcule (so-called because of its shape).

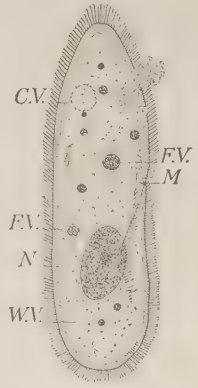
This cell is elongated, oval, or elliptical in outline, but somewhat flattened. Seen under the low power of the microscope, it appears to be extremely active, rushing about now rapidly, now more slowly, but seemingly always taking a definite course. The more pointed end of the body (the *anterior*) usually goes first.

[1] This shows one practical reason why plant food often contains more indigestible matter than animal food of same bulk.

If it pushes its way past any dense substance in the water, the cell body is seen to change its shape as it squeezes through.

The cell body is almost transparent, and consists of semifluid protoplasm which has a granular grayish appearance under the microscope. This protoplasm appears to be bounded by a very delicate membrane through which project numerous delicate threads of protoplasm called *cilia*. (These are usually invisible under the microscope.)

The locomotion of the paramœcium is caused by the movement of these cilia which lash the water like a multitude of tiny oars. The cilia also send tiny particles of food into a funnel-like opening, the *gullet* on one side of the cell. Once within the cell body, the particles of food materials are gathered into little balls within the almost transparent protoplasm. These masses of food seem to be inclosed within a little area containing fluid, called a *vacuole*. Other vacuoles appear to be clear; these are spaces in which food has been digested. One or two larger vacuoles may be found; these are the *contractile vacuoles;* their purpose seems to be to pass off waste material from the cell body. This is done by pulsation of the vacuole, which ultimately bursts, passing fluid waste to the outside. Solid wastes are passed out of the cell in somewhat the same manner. The nucleus of the cell is not easily visible in living specimens. In a cell that has been stained it has been found to be a double structure, consisting of one large and one small portion, called respectively the *macronucleus* and the *micronucleus*.

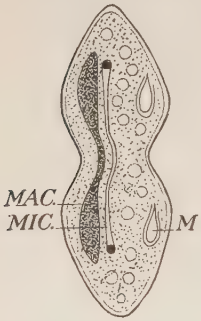


Paramœcium. Greatly magnified. From side. *F.V.*, food vacuole; *C.V.*, contractile vacuole: *M*, mouth; *N*, nucleus; *W.V.*, water vacuole. (After Sedgwick and Wilson.)

Response to Stimuli. — In the paramœcium, as in the one-celled plants, the protoplasm composing the cell can do certain things. Protoplasm responds, in both plants and animals, to certain agencies acting upon it, coming from without; these agencies we call *stimuli*. Such stimuli may be light, differences of temperature, presence of food, electricity, or other factors of its surroundings.

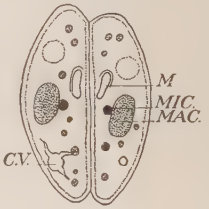
Plant and animal cells may react differently to the same stimuli. In general, however, we know that protoplasm is *irritable* to some of these factors. To severe stimuli, protoplasm usually responds by *contracting*, another power which it possesses. We know, too, that plant and animal cells take in food and change the food to protoplasm, that is, that they *assimilate* food; and that they may waste away and repair themselves. Finally, we know that new plant and animal cells are reproduced from the original bit of protoplasm, a single cell.

Reproduction of Paramœcium. — Sometimes a paramœcium may be found in the act of dividing by the process known as *fission*, to form two new cells, each of which contains half of the original cell. This is a method of *asexual* reproduction. The original cell may thus form in succession many hundreds of cells in every respect like the original parent cell.



Paramœcium dividing by fission. Greatly magnified. *M*, mouth; *MAC.*, macronucleus; *MIC.*, micronucleus. (After Sedgwick and Wilson.)

Frequently another method of reproduction may be observed. This is called *conjugation*, and somewhat resembles the same process in the simple plants. Two cells of equal size attach themselves together as shown in the Figure. Complicated changes take place in the nuclei of the two cells thus united, which results in an equal exchange of part of the material forming the nucleus. After a short period of rest the two cells separate. The stage of conjugation we believed in the plants to be a *sexual* stage. There seems every reason to believe that it is a like stage in the life history of the paramœcium.

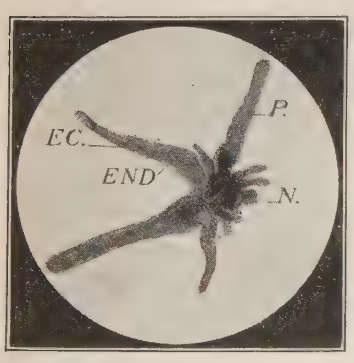


Paramœcium. Greatly magnified. *M*, mouth; *MIC.*, micronucleus; *MAC.*, macronucleus; *C.V*, contractile vacuole. (After Sedgwick and Wilson.)

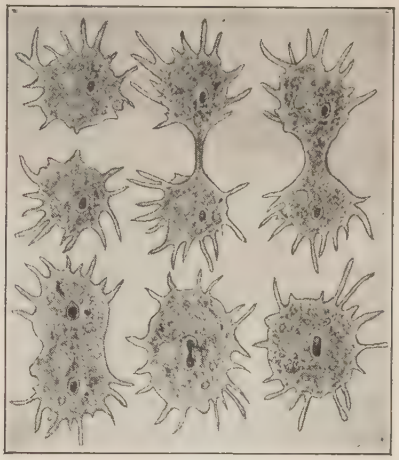
Amœba. — In order to understand more fully the life of a simple bit of protoplasm, let us take up the study of the *amœba*, a type

Amœbæ *may* be obtained from the hay infusion, from the dead leaves in the bottom of small pools, from the same source in fresh-water aquaria, from the roots of

of the simplest form of life known, either plant or animal. Unlike the plant and animal cells we have examined, the amœba has no fixed form. Viewed under the compound microscope, it has the appearance of an irregular mass of granular protoplasm. Its form is constantly changing as it moves about. This is due to the pushing out of tiny projections of the protoplasm of the cell, called *pseudopodia* (false feet). The outer layer of protoplasm is not so granular as the inner part; this outer layer is called *ectoplasm*, the inside being called *endoplasm*. In the central part of the cell is the nucleus. This important organ is difficult to see, except in cells that have been stained.



Amœba, with pseudopodia (*P.*) extended; *EC.*, ectoplasm; *END*, endoplasm; the dark area (*N.*) is the nucleus. From photograph loaned by Professor G. N. Calkins.



Amœba, showing the changes which take place during division. The dark body in each Figure is the nucleus; the transparent circle, the contractile vacuole; the outer, clear portion of the body the ectoplasm; the granular portion, the endoplasm; the granular masses, food vacuoles. Much magnified.

The locomotion is accomplished, according to Professor Jennings of Johns Hopkins University, by a kind of rolling motion, "the upper and lower surfaces constantly interchanging positions." The pseudopodia are pushed forward in the direction which the animal is to go, the rest of the body following.

duckweed or other small water plants, or from green algæ growing in quiet localities. No *sure* method of obtaining them can be given.

Although but a single cell, still the amœba appears to be aware of the existence of food when food is near at hand. Food may be taken into the body at any point, the semifluid protoplasm simply rolling over and engulfing the food material. Within the body, as in the paramœcium, the food is inclosed within a fluid space or vacuole. The protoplasm has the power to take out such material as it can use to form new protoplasm or give energy. It will then rid itself of any material that it cannot use. Thus it has the power of *selective absorption*, a character found in the protoplasm of plants previously studied. Circulation of food material is accomplished by the constant streaming of the protoplasm within the cell.

The cell absorbs oxygen from the water by osmosis through its delicate membrane, giving up carbon dioxide in return. Thus the cell "breathes" through any part of its body covering.

Waste products formed from the oxidations which take place in the cell are passed out by means of the contractile vacuole.

The amœba, like other one-celled organisms, reproduces by the process of fission. A single cell divides by splitting into two others, each of which resembles the parent cell, except that they are of less bulk. When these become the size of the parent amœba, they in turn each divide. This is a kind of asexual reproduction.

When conditions unfavorable for life come, the amœba, like some one-celled plants, encysts itself within a membranous wall. In this condition it may become dried and be blown through the air. Upon return to a favorable environment, it begins life again, as before. In this respect it resembles the spore of a plant.

From the study of the amœbalike organisms which are known to cause malaria, and by comparison with the amœbæ which live in our ponds and swamps, it seems likely that every amœba has a complicated life history during which it passes through a *sexual* stage of existence.

The Cell as a Unit. — In the daily life of a one-celled animal we find the single cell performing all the general activities which we shall later find the many-celled animal is able to perform. In the amœba no definite parts of the cell appear to be set off to perform certain functions; but any part of the cell can take in food, can absorb oxygen, can change the food into protoplasm and excrete

the waste material. The single cell is, in fact, an organism able to carry on the business of living as effectually as a very complex animal.

Complex One-celled Animals. — In the paramœcium we find a single cell, but we find certain parts of the cell having certain definite functions : the cilia are used for locomotion ; a definite part of the cell takes in food, while the waste passes out at another definite spot. In another one-celled animal called *vorticella*, part of the cell has become elongated and is contractile. By this stalk the little animal is fastened to a water plant or other object. The stalk may be said to act like a muscle fiber, as its sole function seems to be movement ; the cilia are located at one end of the cell and serve to create a current of water which will bring food particles to the mouth. Here we have several parts of the cell each doing a different kind of work. This is known as *physiological division of labor.*

Photograph of a living bell animalcule (*vorticella*) enlarged two hundred diameters. Notice the contractile stalk and the circle of cilia about the mouth.

Habitat of Protozoa. — Protozoa are found almost everywhere in shallow water, seemingly never at any great depth. They appear to be attracted near to the surface by light and the supply of oxygen. Every fresh-water lake swarms with them; the ocean contains countless myriads of many different forms.

Use as Food. — They are so numerous in lakes, rivers, and the ocean as to form the food for many animals higher in the scale of life. Almost all fish that do not take the hook and that travel in schools, or companies, migrating from one place to another, live partly on such food. Many feed on slightly larger animals, which in turn eat the Protozoa. Such fish have on each side of the mouth attached to the gills a series of small structures looking like tiny rakes. These are called the gill rakers, and aid in collecting

tiny organisms from the water as it passes over the gills. The whale, the largest of all mammals, strains protozoans and other small animals and plants out of the water by means of hanging plates of whalebone, the slender filaments of which form a sieve from the top to the bottom of the mouth.

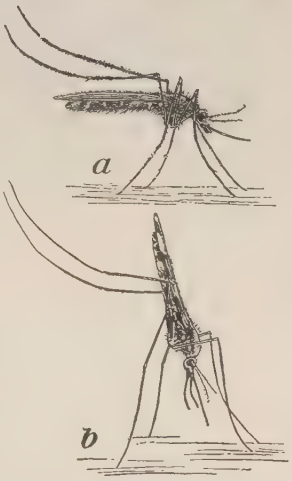
Relation of Protozoa to Disease. — The study of the life history and habits of the Protozoa has resulted in the finding of many parasitic forms, and the consequent explanation of some kinds of disease. One parasitic protozoan like an amœba is called *Plasmodium malariæ*. It causes the disease known as malaria. Part of its life is passed within the body of a mosquito (the *anopheles*), into the stomach of which it passes when the mosquito sucks the blood from a person having malaria. Within the body of the mosquito a complicated part of the life history takes place, which results in a stage of the parasite establishing itself within the glands which secrete the saliva of the mosquito. When the mosquito pierces its human prey a second time, some of the parasites are introduced into the blood along with the saliva. These parasites enter the corpuscles of the blood, increase in size, and then form spores. The rapid process of spore formation results in the chill of malaria. Later, when the spores almost fill the blood corpuscle, it bursts, and the parasites enter the fluid portion of the blood. There they release a poison which causes the fever. The spores may again enter the blood corpuscles and in forty-eight or seventy-two hours repeat the process thus described. Yellow fever is undoubtedly conveyed by another species of mosquito, and is probably due to the presence of a protozoan similar to that of malaria in the blood. That these diseases may be stamped out by the destruction of the mosquitoes, by preventing their breed-

Blood corpuscles of a patient with malarial fever. Two corpuscles contain the parasites. Photograph, greatly enlarged, by Davison.

ing in swamps with the use of oil, by draining the swamps, or by the introduction of fish which eat the mosquito larvæ has been proved from our experiences along the Panama Canal, in the Philippines, in Cuba, and in New Orleans.

Many other diseases of man are probably caused by parasitic protozoans. Dysentery of one kind appears to be caused by the presence of an amœbalike animal in the digestive tract. Smallpox, rabies, and possibly other diseases may be caused by the action of these little animals.

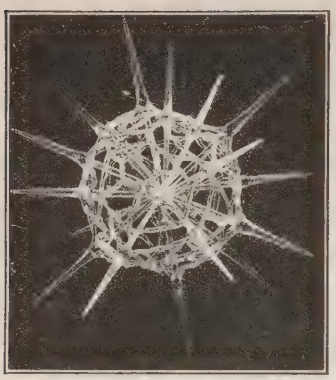
Another group of protozoan parasites are called *trypanosomes*. One of this family lives in the blood of native African zebras and antelopes; seemingly it does them no harm. But if one of these parasites is transferred by the dreaded tsetse fly to one of the domesticated horses or cattle of the colonist of that region, death of the animal results.



How to tell the common mosquito (*culex*), *a*, from the malarial mosquito (*anopheles*), *b*, when at rest. Note the position of body and legs.

Another fly carries a specimen of trypanosome to the natives of Central Africa, which causes "the dreaded and incurable sleeping sickness." This disease carries off more than fifty thousand natives yearly, and many Europeans have succumbed to it. Its ravages are now largely confined to an area near the large Central African lakes and the Upper Nile, for the fly which carries the disease flies near water, seldom going more than 150 feet from the banks of streams or lakes. The British government is now trying to control the disease in Uganda by moving all the villages at least two miles from the lakes and rivers. Why? In this country many fatal diseases of cattle, as "tick," or Texas fever, among cattle are probably caused by protozoans.

Skeleton Building. — Some of the Protozoa build elaborate skeletons. These may be formed outside of the body, being composed of tiny micro-



Skeleton of a radiolarian. Highly magnified. From model at American Museum of Natural History.

scopic grains of sand, or other materials. In some forms the skeleton is internal, and may be made of lime which the animals take out of the water. Still other Protozoa construct shells which house them for a time; then, growing larger, they add more chambers to their shell, forming ultimately a covering of great beauty. These shells or skeletons of Protozoa, falling to the sea bottom, cover the ocean floor to a depth of several feet in places.

The Protozoa have also played an important part in rock building. The chalk beds of Kansas and other chalk formations are made up to a large extent of the tiny skeletons of *Protozoa*, called *Foraminifera*. Some limestone rocks are also composed in large part of such skeletons.

Classification of Protozoa

The following are the principal classes of Protozoa, examples of which we have seen or read about: —

Class I. *Rhizopoda* (Gk.=*root-footed*). Having no fixed form, with pseudopodia. Either naked as *Amœba* or building limy (*Foraminifera*) or glasslike skeletons (*Radiolaria*).

Class II. *Infusoria* (*in infusions*). Usually active ciliated Protozoa. Examples, *Paramœcium*, *Vorticella*.

Class III. *Sporozoa* (*spore animals*). Usually parasitic and nonactive. Example, *Plasmodium malariæ*.

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XVI. SIMPLE METAZOA — DIVISION OF LABOR

Problem XXVI. *An introductory study of many-celled animals.* (*Laboratory Manual, Prob. XXVI.*)

(*a*) *Development.*
(*b*) *Sponges.*
(*c*) *The hydra.*
(*d*) *Development of tissues and organs.*
(*e*) *Common functions.*

Reproduction in Simple Plants. — Although there are very many plants and animals so small and so simple as to be composed of but a single cell, by far the greater part of the animal and plant world is made up of individuals which are collections of cells living together.

In a simple plant like the pond scum, a string or filament of cells is formed by a single cell dividing crosswise, the two cells formed give rise each to two more, and eventually a long thread of cells results. Such growth of cells is asexual.

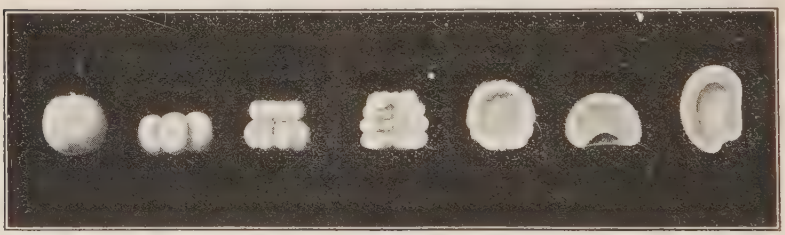
In some instances, however, a single cell was formed by the union of two cells, one from each of the adjoining filaments of the plant. Around this cell eventually a hard coat was formed, and the *spore,* as it was called, was thus protected from unfavorable changes in the surroundings. Later, when conditions became favorable for its germination, the spore might form a new filament of pond scum.

In the seed plants, too, we found a little plant within the seed which, under favorable conditions, might give rise, through the rapid multiplication of the cells forming it, to a new plant. But the plant within the seed first arose from two cells, one of which, called a sperm, came from a pollen grain, the other of which, the egg, was found within the embryo sac of the ovary.

Reproduction in Simple Animals. — Similarly, in the reproduction of many-celled animals the new animal is formed by the

union of a sperm and an egg cell. A common bath sponge, an earthworm, a fish, or a dog, — each and all of them begin life in precisely the same way. Animals which are thus composed of many cells are known as the *Metazoa*, as distinguished from the *Protozoa*, which are made of but a single cell.

Sexual Development of a Simple Animal. — In a many-celled animal the life history begins with a single cell, the fertilized egg. This cell, as we remember, has been formed by the union of two other cells, a tiny (usually motile) cell, the *sperm*, and a large cell, the *egg*. After the egg is fertilized by a sperm cell, it splits into two, four, eight, and sixteen cells; as the number of cells increases, a hollow ball of cells called the *blastula* is formed; later this ball sinks



Stages in the segmentation of an egg, showing the formation of the gastrula.

in on one side, and a double-walled cup of cells, now called a *gastrula*, results. Practically all animals pass through the above stages in their development from the egg, although these stages are often not plain to see because of the presence of food material (yolk) in the egg. In the sponge the gastrula, which swims by means of cilia, soon settles down, a skeleton is formed, other changes take place, and the sponge begins life as an animal attached to some support on the water. The early stages of life, when an animal is unlike the adult, are known as *larval* stages; the animal at this time being called a larva.

The young sponge consists of three layers of cells: those of the outside, developed from the outer layer of the gastrula, are called *ectoderm;* the inner layer, developed from the inner layer of the gastrula, the *endoderm*. A middle almost structureless layer, called the *mesoderm*, is also found. In higher animals this layer gives rise to muscles and parts of other internal structures.

The Structure of a Sponge. — The simplest kind of a sponge has the form of an urn, attached at the lower end. A common sponge living in Long Island Sound is a tiny urn-shaped animal less than an inch in length. It has a skeleton made up of very tiny spicules of lime, of different shapes. Cut lengthwise, such an animal is seen to be hollow, its body wall being pierced with many tiny pores or holes. The bath sponge, the skeleton of which is made up of fibers of horn, or a variety known as the finger sponge, shows the pores even better than the smaller limy sponge. In a bath sponge, however, we probably have a colony of sponges living together. Each sponge has a large number of pores opening into a central cavity, which in turn opens by a larger hole, called the osculum, to the surrounding water.

A horny fiber sponge: *IP*, the incurrent pores; *O*, osculum. Notice that this sponge is made up of apparently several individuals. One fourth natural size.

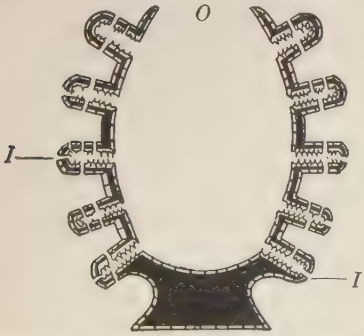
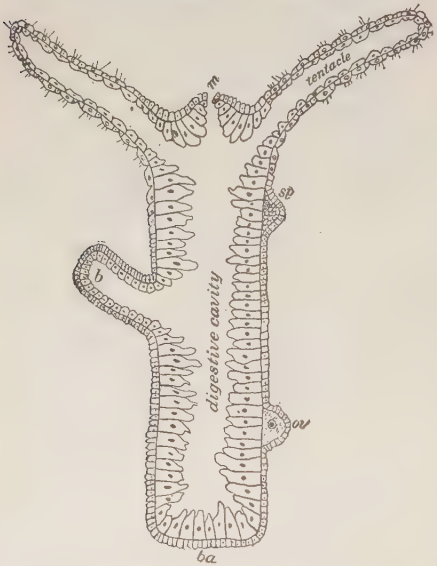


Diagram of a simple sponge: *I*, inhalant openings; *O*, exhalant opening or *osculum*.

A microscopic examination shows the pores of the sponge to be lined on the inside with cells having a collar of living matter surrounding a single long cilium or *flagellum*. The flagella, lashing in one direction, set up a current of water toward the large inner cavity. This current bears food particles, tiny plants and animals, which are seized and digested by the collared cells, these cells probably passing on the food to the other cells of the body. The jellylike middle layer of the body is composed of cells which secrete lime to form the spicules and the reproductive cells, eggs, and sperms.

The Hydra. — Another very simple animal, which unlike the sponge lives in fresh water,[1] is called the hydra. This little creature is shaped like a hollow cylinder with a circle of arms or *tentacles* at the free end. It is found attached to dead leaves, sticks, stones, or water weed in most fresh-water ponds. When disturbed they contract it into a tiny whitish ball little larger than the head of a pin. Expanded, it may stretch its tentacles in search of food almost an inch from their point of attachment. The tentacles are provided with batteries of minute darts or stinging cells, by means of which prey is caught and killed. The outer layer of the animal serves for protection as well as movement and sensation, certain cells being fitted for each of those different purposes.



Longitudinal section of a hydra: *b*, bud; *ba*, attached end; *m*, mouth; *ov*, ovary; *sp*, spermary holding sperm cells.

Food Taking. — The tentacles then reach out like arms, grasp the food, and bend over with it toward the mouth. Certain cells lining the hollow digestive cavity pour out a fluid which aids in digesting the food. Other cells with long cilia circulate the food, while still other cells lining the cavity put out pseudopodia, which grasp and ingest the food particles. The tentacles are hollow, and the digestive cavity extends into them. The outer layer of the animal does not digest the food, but receives some of it already digested from the inner layer. This food passes from cell to cell, as in plants, by osmosis. The oxygen necessary to oxidize the food is passed through the body wall, seemingly at any point, for there are no organs for respiration (breathing).

[1] A few sponges, for example, spongilla, live in fresh water.

Reproduction. — The hydra reproduces itself either by budding or by the production of new animals by means of eggs and sperms, sexually. The bud appears on the body as a little knob, sometimes more than one coming out on the same hydra. At first the bud is part of the parent animal, the body cavity extending into it. After a short time (usually a few days) the young hydra separates from the old one and begins life anew. This is asexual reproduction.

The hydra also reproduces by eggs and sperms. These sperms are collected in little groups which usually appear near the free end of the animal, the egg cells developing near the base of the same hydra. Both eggs and sperms grow from the outer layer of the animal. The sperms, when ripe, are set free in the water; one of them unites with an egg, which is usually still attached to the body of the hydra, and development begins which results in the growth of a new hydra in a new locality.

The stages passed through in development resemble closely those already described on page 200, and it would not be hard to imagine the gastrula stage, turned upside down with a circle of tentacles at the open end. Our gastrula would then be a hydra.

Division of Labor. — If we compare the amœba and the paramœcium, we find the latter a more complex organism than the former. An amœba may take in food through any part of the body; the paramœcium has a definite gullet; the amœba may use any part of the body for locomotion; the paramœcium has definite parts of the cell, the cilia, fitted for this work. Since the structure of the paramœcium is more complex, we say that it is a "higher" animal. In the vorticella, a still more complex cell, part of the cell has grown out like a stalk, has become contractile, and acts and looks like muscle.

As we look higher in the scale of life, we invariably find that certain parts of a plant or animal are set apart to do certain work, and only that work. Just as in a community of people, there are some men who do rough manual work, others who are skilled workmen, some who are shopkeepers, and still others who are professional men, so among plants and animals, wherever *collections* of cells live together to form an organism, there is division of labor, some cells being fitted to do one kind of work, while others are fitted to do work of another sort.

As we have seen in plants, this results in a large number of collections of cells in the body, each collection alike in structure and performing the same function. Such a collection of cells we call a *tissue*. (See Chapter III.)

Frequently several tissues have certain functions to perform in conjunction with one another. The arm of the human body performs movement. To do this, several tissues, as muscles, nerves, and bones, must act together. A collection of tissues performing certain work is called an *organ*.

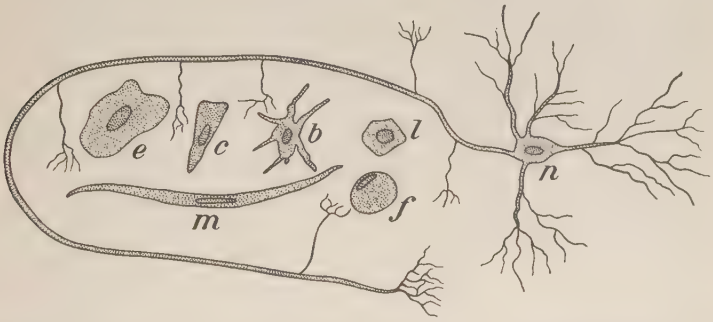
In the sponge, division of labor occurs between the cells of the simple animal, some cells lining the incurrent pores creating a current of water, and feeding upon the minute organisms which come within reach, other cells building the skeleton of the sponge, still others becoming eggs or sperms. Division of labor of a more complicated sort is seen in the hydra. Here the cells which do the same kind of work are collected into tissues, each tissue being a collection of cells, all of which are more or less alike and do the same kind of work. But in higher animals which are more complicated in structure and in which the tissues are found working together to form organs, division of labor is still more developed. In the human arm, an organ fitted for certain movements, think of the number of tissues and the complicated actions which are possible. The most extreme division of labor is seen in the organism which has the most complex actions to perform and whose organs are fitted for such work.

In our daily life in a town or city we see division of labor between individuals. Such division of labor may occur among other animals, as, for example, bees or ants. But it is seen at its highest in a great city or in a large business or industry. In the stockyards of Chicago, division of labor has resulted in certain men performing but a single movement during their entire day's work, but this movement repeated so many times in a day has resulted in wonderful accuracy and increased speed. Thus division of labor obtains its end.

Tissues in the Human Body. — Every animal body above the protozoan is composed of a certain number of tissues. The cells making up these tissues have certain well-defined characteristics. In very simple animals the cells are all very much alike, but in more

complex animals the cells are more and more unlike as their work becomes more and more different. Let us see what these cells may be, what their structure is, and, in a general way, what function each has in the human body.

Muscle Cells. — A large part of our body is made up of muscle. Muscle cells are elongated in shape, and have great contractile power. Their work is that of causing movement, and this is usually done by means of attachment to a skeleton inside the body. In man they may be of two kinds, *voluntary* (under control of the will) and *involuntary*.



Diagrams of sections of cells, greatly magnified. *e*, flat cell (epithelium) from mouth ; *c*, columnar epithelium from food tube ; *b*, bone-forming cell ; *l*, liver cell ; *m*, muscle cell ; *f*, fat cell ; *n*, nerve cell.

Epithelial Cells. — Such cells cover the outside of a body or line the inside of the cavities in the body. The shape of such cells varies from flat plates to little cubes or columns depending upon their position inside or outside the body. Some bear cilia, an adaptation. Can you think of their purpose?

Connective Tissue Cells. — Such cells form the connection between tissues in the body. They are characterized by possessing numerous long processes. They also secrete, as do many other cells, a substance like jelly, called *intercellular* substance. This stands in the same relation to the cells as does mortar to the bricks in a wall.

Several other types of cells might be mentioned, as blood cells, cartilage cells, bone cells, and nerve cells. A glance at the Figure shows their great variety of shapes and sizes.

Functions Common to All Animals. — The same general functions performed by a single cell are performed by a many-celled animal. But in the Metazoa the various functions of the single cell are taken up by the organs. In a complex organism, like man, the organs and the functions they perform may be briefly given as follows: —

(1) The organs of *food taking:* food may be taken in by individual cells, as those lining the pores of the sponge, or definite parts of a food tube may be set apart for this purpose, as the mouth and parts which place food in the mouth.

(2) The organs of *digestion:* the food tube and collections of cells which form the glands connected with it. The enzymes in the fluids secreted by the latter change the foods from a solid form (usually insoluble) to that of a *fluid.* Such fluid may then pass by osmosis through the walls of the food tube into the blood.

(3) The organs of *circulation:* the tubes through which the blood, bearing its organic foods and oxygen, reaches the tissues of the body. In simple forms of Metazoa, as the sponge and hydra, no such organs are needed, the fluid food passing from cell to cell by osmosis.

(4) The organs of *respiration:* the organs in which the blood receives oxygen and gives up carbon dioxide. The outer layer of the body serves this purpose in very simple animals; gills or lungs are developed in more complex animals.

(5) The organs of *excretion:* such as the kidneys and skin, which pass off nitrogenous and other waste matters from the body.

(6) The organs of *locomotion:* muscles and their attachments and connectives; namely, tendons, ligaments, and bones.

(7) The organs of *nervous control:* the central nervous system, which has control of coördinated movement. This consists of scattered cells in low forms of life; such cells are collected into groups and connected with each other in higher animals.

(8) The *sense organs:* collections of cells having to do with the reception of sight, hearing, smell, taste, and touch.

(9) The organs of *reproduction:* the sperm and egg-forming glands.

Almost all animals have the functions mentioned above. In most, the various organs mentioned are more or less developed, although in the simpler forms of animal life some of the organs mentioned above are either very poorly developed or entirely lacking.

FORMS OF SIMPLE METAZOANS. SPONGES

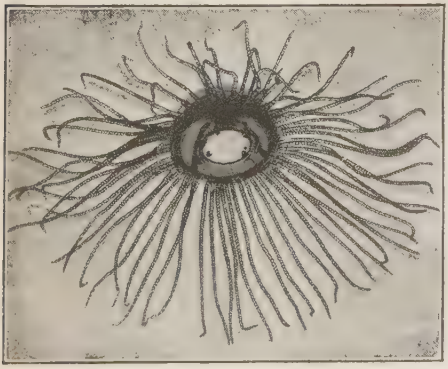
Sponges may be placed, according to the kind of skeleton they possess, in the following groups: —

(1) The limy sponges, in which the skeleton is composed of spicules of carbonate of lime. Grantia is an example.

(2) The glassy sponges. Here the skeleton is made of silica or glass. Some of the rarest and most beautiful of all sponges belong in this class. The Venus's flower basket is an example.

Venus's flower basket; a sponge with a glassy skeleton.

(3) The horny fiber sponges. These, the sponges of commerce, have the skeleton composed of tough fibers of material somewhat like that of cow's horn. This fiber is elastic and has the power to absorb water. In a living state, the horny fiber sponge is a dark-colored fleshy mass, usually found attached to rocks. The warm waters of the Mediterranean Sea and the West Indies furnish most of our sponges. The sponges are pulled up from their resting place on the bottom, either by means of long-handled rakes operated by men in boats, or are secured by divers. They are then spread out on the shore in the sun, and the living tissues allowed to decay; then after treatment consisting of beating, bleaching, and trimming, the bath sponge is ready for the market.

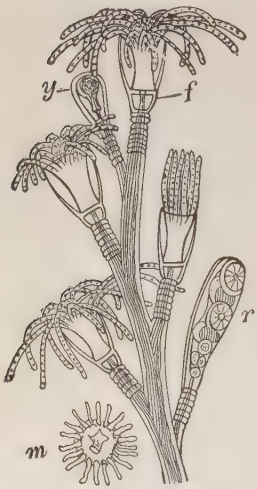


Medusa (*Gonionemus murbachii*), showing tentacles, mouth, digestive canals, and reproductive bodies. Photographed from the model at the American Museum of Natural History.

CŒLENTERATES

The hydra and its salt-water allies, the jellyfish, hydroids, and corals, belong to a group of animals known as the *Cœlenterata*. The word "cœlenterate" (*cœlom* = body cavity, *enteron* = food tube) explains the structure of the group. They are animals in which the real body cavity is lacking, the animal in its simplest form being little more than a bag.

Medusa. — Among the most interesting of all the cœlenterates inhabiting the salt water are the jellyfishes or medusæ. These animals vary greatly in size from a tiny umbrella-shaped animal little larger than the head of a pin to huge jellyfish several feet in diameter.



A hydroid colony of six polyps: *f*, feeding polyp; *r*, reproductive polyp; *m*, a medusa; *y*, young polyp.

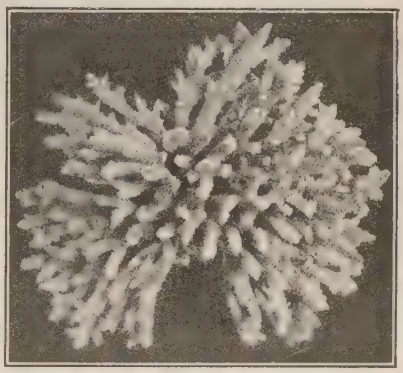
Development. — Many species of medusæ pass through another stage of life. As medusæ they reproduce by eggs and sperms, that is, sexually. The egg of the medusa segments, forming ultimately a ball of cells (the *blastula*) which swims around by means of cilia. Ultimately the little animal settles down on one end and becomes fixed to a rock, seaweed, or pile. The free end becomes indented in the same manner as a hollow rubber ball may be pushed in on one side. This indented side becomes a mouth, tentacles develop around the orifice, and we have an animal that looks very much like the hydra. This animal, now known as a *hydroid polyp*, buds rapidly and soon forms a colony of little polyps, each of which is connected with its neighbor by a hollow food tube. The hydroid polyp differs from its fresh-water cousin, the hydra, by usually possessing a tough covering which is not alive.

Alternation of Generations in Cœlenterates. — The lives of a hydroid and a medusa are seen thus to be intimately connected with each other. A hydroid colony produces new polyps by budding. This we know is an *asexual* method of reproduction. There come from this hydroid colony, however, little buds which give rise to medusæ. These medusæ produce eggs and sperms. Their reproduction is *sexual*, as was the reproduction by means of eggs and sperms from the prothallus of the fern. So we have in animals, as well as in plants, an alternation of generations.

Sea anemone. About one half natural size. The right-hand specimen is expanded. Note the mouth surrounded by the tentacles. The left-hand specimen is contracted. From model at the American Museum of Natural History.

Sea Anemone. — Those who have visited our New England coast are familiar with another cœlenterate called the sea anemone. This animal gets its name

because, when expanded, it looks like a beautiful flower of a golden yellow or red color. The body of the sea anemone is like the hydra, a column attached at one end. The free end is provided with a mouth surrounded with a great number of tentacles. These, when expanded, look like the petals of a flower. The sea anemone is a very voracious flower, for by means of the batteries of stinging cells in its tentacles it is able to catch and devour fishes and other animals almost as large as itself. When disturbed or irritated, the animal contracts into a slimy ball, making it difficult to dislodge from its attachment.



A branching madreporic coral.

Although the sea anemone is like a large hydra in appearance, its interior is different. The hollow digestive cavity contains a number of partitions more or less complete, which run from the outer wall toward the middle of the cavity. These partitions, known as mesenteries, are found in pairs. Part of the cavity, as in the hydra, is given up to digesting the food. Food is killed by means of stinging cells found in the long threadlike tentacles.

Coral. — If a piece of madreporic coral is examined with a hand lens, a number of little depressions will be seen in the limy surface, each of which has tiny partitions within it.

A single coral cup, showing the walls of lime built by the mesenteries. From a photograph loaned by the American Museum of Natural History.

These cuplike depressions were once occupied by the coral animals or polyps, each in its own cup. The mesenteries of the coral polyp are paired and hollow on the under surface. The partitions seen in the coral cups lie between the pairs of mesenteries, and are formed by them when the animal is alive. Sea water has a considerable amount of lime in its composition. This lime (calcium carbonate) is taken from the water by certain of the cells of the coral polyp and deposited around the base of the animal and between the mesenteries, thus giving the appearance just seen in the cups of the coral branch.

Asexual Reproduction. — These polyps reproduce by budding, and when alive cover the whole coral branch with a continuous living mass of

polyps, each connected with its neighbor. In this way great masses of coral are formed. Coral, in a living state, is alive only on the surface, the polyps building outward on the skeleton formed by their predecessors.

Economic Importance of Corals. — Only one (astrangia) of a great many different species of coral lives as far north as New York. In tropical waters they are very abundant. Coral building has had and still has an immense influence on the formation of islands, and even parts of continents in tropical seas. Not only are many of the West Indian islands composed largely of coral, but also Florida, Australia, and the islands of the southern Pacific are almost entirely of coral formation.

Coral Reefs. — The coral polyp can live only in clear sea water of moderate depth. Fresh water, bearing mud or other impurities, kills them immediately. Hence coral reefs are never found near the mouths of large fresh-water rivers. They are frequently found building reefs close to the shore. In such cases these reefs are called fringing reefs. The so-called barrier reefs are found at greater distance (sometimes forty to fifty miles) from the shore. An example is the Great Barrier Reef of Australia. The typical coral island is called an atoll. It has a circular form inclosing a part of the sea which may or may not be in communication with the ocean outside the atoll. The atoll was perhaps at one time a reef outside a small island. This island disappeared, probably by the sinking of the land. The polyps, which could live in water up to about one hundred and fifty feet, continued to build the reef until it arose to the surface of the ocean. As the polyps could not exist for long above low-water line, the animals died and their skeletons became disintegrated by the action of waves and air. Later birds brought a few seeds there, perhaps a coconut was washed ashore; thus plant life became established in the atoll, and a new outpost to support human life was established.

Classification of Cœlenterates

Class I. *Hydrozoa.* Body cavity containing no mesenteries, usually alternation of generation. Examples: *Hydra*, hydroids.

Class II. *Scyphozoa.* Examples: large jellyfishes.

Class III. *Actinozoa.* Mesenteries present in body cavity. Examples: sea anemones and corals.

Class IV. *Ctenophora.*

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XVII. THE WORMS, A STUDY OF RELATIONS TO ENVIRONMENT

Problem XXVII. *The relation of the earthworm to its surroundings (optional). (Laboratory Manual, Prob. XXVII.)*

Effect of Surroundings on Plants. — Animals as well as plants are influenced very greatly by their surroundings or environment. We have seen how green plants behave toward the various factors of their environment; how heat and moisture start germination in a seed; how the roots grow toward water; how gravity influences the root and the stem, pulling the root downward and stimulating the stem to grow upward; how the stem grows toward the source of light; and how the leaves put their flat surfaces so as to get as much light as possible; and how oxygen is necessary for life to go on.

It is quite possible to show that the factors of environment act upon animals as well as plants, although it is much harder to explain why an animal does a certain thing at a certain time.

How One-celled Animals respond to Stimuli. — We have seen that the single-celled animals respond to certain stimuli in their surroundings The presence of food attracts them; when they run into an object, they respond immediately by backing away, thus showing that they have a sense of touch. If part of a glass slide containing paramœcia is heated slightly, the animals will respond to the increase in heat by moving toward the cooler end. Many other experiments might be quoted to show that the living matter of a simple animal is sensitive to its surroundings.

The Earthworm in its Relation to its Surroundings. — The earthworm, familiar to most boys as bait, shows us in many ways how a many-celled animal responds to stimuli. Careful observation of the body of a living earthworm shows us that its long tapering body is made up of a large number of rings or segments. The number of these segments will be found to vary in worms of different size, the larger worms having more segments.

If the two ends of the worm be touched lightly with a small stick

or straw, one end will be found to respond much more readily to touch than the other end. The more sensitive end is the front or *anterior* end, the other end being the posterior end. Jar the dish in which the worm is crawling; it will immediately respond by contracting its body.

Living earthworms tend to collect along the sides of a dish or in the corners. This seems to be due to an instinct which leads them to inhabit holes in the ground.

An earthworm placed half in and half out of a darkened box soon

An earthworm crawling over a smooth surface.

responds by crawling into the darkened part and remaining there. There are no eyes visible. A careful study of the worm with the microscope, however, has revealed the fact that scattered through the skin, particularly of the anterior segments, are many little structures which not only enable the animal to distinguish between light and darkness, but also light of low and high intensity, as well as the direction from which it comes. A worm has no ears or special organs of feeling. We know, however, that although a worm responds to vibrations of low intensity, the sense of touch is well developed in all parts of the body.

It also responds to the presence of food, as can be proved if bits of lettuce or cabbage leaf are left overnight in a dish of earth where worms are kept.

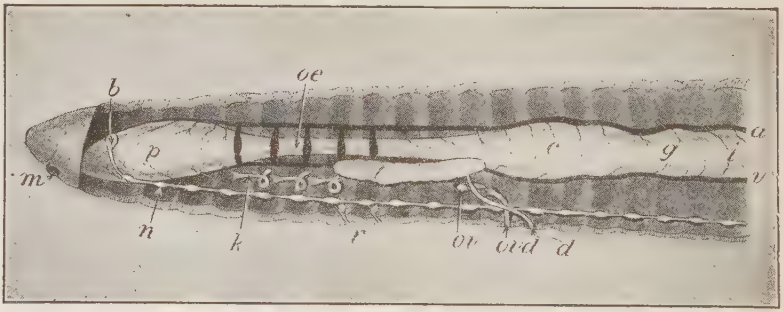
Locomotion of an Earthworm. — If we measure an earthworm when it is extended and compare with the same worm contracted, we note a difference in length. This is accounted for when we understand the method of locomotion. Under the skin are two sets of muscles, an outer set which passes in a circular direction

around the body, and an inner set which runs the length of the body. The body is lengthened by the contraction of the circular muscles. How might the body be shortened?

Diagram to show how movement of a seta is accomplished; *M*, muscles; *S*, seta; *W*, body wall. (After Sedgwick and Wilson.)

The under surface of the worm is provided with four double rows of tiny bristles called setæ, every segment except the first three and the last being provided with setæ. Each seta has attached to it small muscles, which turn the seta so it may point in the opposite direction from which the worm is moving. If you watch a specimen carefully, you will see that locomotion is accomplished by the thrusting forward of the anterior end; then a wave of muscular contraction passes down the body, thus shortening the body by drawing up the posterior end. The setæ at the anterior end serve as anchors which prevent the body from slipping backward as the posterior end is drawn up.

How the Worm digs Holes. — A feeding worm will show the proboscis, an extension of the upper lip which is used to push food into the mouth.

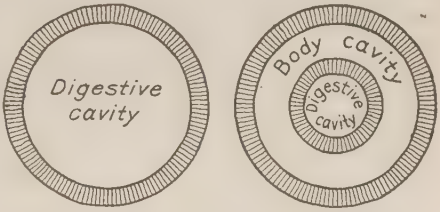


Forepart of an earthworm with the left body wall removed to show the body cavity and food tube within it: *m*, mouth; *p*, pharynx, *c*, *g*, *i*, food tube.

The earthworm is not provided with hard jaws or teeth. Yet it literally eats its way through the hardest soil. Inside the mouth opening is a part of the food tube called the pharynx. This is very muscular so that it can be extended and withdrawn by the worm. When applied to the surface of the soil, which is first moistened by the worm, it acts as a suction pump and draws it into the food tube. As the worms take organic matter out of the ground as food, they pass the earth through the body in order to

get this food. The earth is mixed with fluids poured out from glands in the food tube, and is passed out of the body and deposited on the surface of the ground, in the form of little piles of moist earth. These are familiar sights on all lawns; they are called worm casts. Charles Darwin calculated that fifty-three thousand worms may be found in an acre of ground, that ten tons of soil might pass through their bodies in a single year and thus be brought to the surface, and that they plow more soil than all the farmers put together. Earthworms, in spite of their fondness for some garden vegetables and young roots, do much good by breaking up the soil, thus allowing water and oxygen to penetrate to the roots of plants.

Comparison between Hydra and Worm. — The digestive tract of the worm is an almost straight tube inside of another tube. The latter is divided by partitions which mark the boundary of each segment. The outer cavity is known as the *body cavity*. In the hydra no body cavity exists, there being only a digestive cavity.



Diagrammatic cross section of the body of a cœlenterate, and that of a worm.

In the animals higher than the cœlenterates the digestive tract and body cavity are distinct. Food is digested within the food tube, is passed through the walls of this tube into the body cavity, and is in part carried by the blood to various parts of the body. No gills or lungs are present, the thin skin acting as an organ of respiration. But the worm is unable to take in oxygen unless the membranelike skin is kept moist.

Development. — Notice in some worms the swollen area called the girdle (about one third the distance from the anterior end). This area periodically forms a little sac in which the eggs of the worm are laid. As it passes toward the anterior end of the worm, it receives from the body openings the sperms and a nutritive fluid in which the eggs live. The fertilized eggs are then left to hatch. The capsules may be found in manure heaps, or under stones, in May or June; they are small yellowish or brown bags about the diameter of a worm.

Regeneration. — If a one-celled animal be cut into two pieces, each piece, if it contains part of the nucleus, will grow into a whole cell. The hydra, some hydroids, jellyfish, and flatworms, if injured, may grow again parts that are lost. This power is known as *regeneration*. Earthworms possess to a large degree the power of replacing parts lost through accident or other means. The anterior end may form a new posterior end, while the posterior end must be cut anterior to the girdle to form a new anterior end. This seems to be in part due to the greater complexity of the organs in the anterior end.

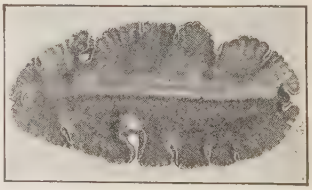
The Sandworm. — Other segmented worms are familiar to some of us. The sandworm, used for bait along our eastern coast, is a segmented worm which lives between tide marks in sandy localities. It is plainly segmented, each segment bearing a pair of locomotor organs called *parapodia* (meaning side feet). A part of each parapodium is prolonged into a triangular gill. The animal has a distinct head, which is provided with tentacles, palps, and eye spots. The mouth has a pair of hard jaws which may be protruded. In this way the animal seizes and draws prey into its mouth. The sandworm swims near the surface of the water, the body bending in graceful undulations as the parapodia, like little oars, force the worm forward. They spend much of the time in tubes in the sand, which are constructed in part of slime excreted from the body of the worm.

The sandworm (*nereis*).

The Leech. — The common leech or bloodsucker is a flattened segmented worm, inhabiting fresh-water ponds and rivers. The adult is provided with two sucking disks, by means of which it fastens itself to objects. The mouth is on the lower surface close to the anterior disk. Locomotion is accomplished by swimming or by means of the suckers, somewhat after the manner of a measuring worm. They feed greedily and are often found gorged with blood, which they suck from the body of the victim. Discomfort, but no danger, attends the bite of the bloodsucker, so dreaded by the small boy.

Problem XXVIII. *A study of some animal associations.* (*Laboratory Manual, Prob. XXVIII.*)

Some Worms which harm Man. — Some worms are unsegmented; such are the flatworms and roundworms. A common leaflike form of flatworm may be found clinging to stones in our fresh-water ponds or brooks. Most flatworms are, however, parasites on other animals; that is, they obtain food and shelter from some other living creature, but give them no benefits in return. Parasitism is one-sided, the host giving everything, the parasite receiving everything. Consequently, the parasite frequently becomes fastened to its host during adult life



A flatworm (*Yungia Aurantiaca*), much magnified. From model in the American Museum of Natural History.

and often is reduced to a mere bag through which the fluid food prepared by its host is absorbed. Such animals as have lost power to move about freely, or are otherwise changed by their surroundings, are said to have *degenerated*.

Sometimes a complicated life history has arisen from their parasitic habits. Such is seen in the life history of the liver fluke, a flatworm which kills sheep, and in the tapeworm.

Cestodes or Tapeworms. — These parasites infest man and many other vertebrate animals. The tapeworm (*Tænia solium*) passes through two stages in its life history, the first within a pig, the second within the intestine of man. The eggs of the worm are taken in with the pig's food. The worm develops within the intestine of the pig, but soon makes its way into the muscles. If man eats pork containing these worms, he may become a host for the tapeworm. Another common tapeworm parasitic on man lives part of its life as an embryo within the muscles of cattle. The adult worm consists of a round headlike part provided with hooks, by means of which it fastens itself to the wall of the intestine. This head now buds off a series of segmentlike structures, which are practically bags full of eggs. These structures, called *proglottids*, break off from time to time, thus allowing the eggs to escape. The proglottids have no separate digestive systems, but the whole body surface, bathed in digested food, absorbs it and is thus enabled to grow rapidly.

Roundworms. — Still other wormlike creatures called roundworms are of importance to man. Some, as the vinegar eel found in vinegar, or the pinworms parasitic in the lower intestine, particularly of children, do little or no harm. The pork worm or *trichina*, however, is a parasite which may cause serious injury. It passes through the first part of its existence as a parasite in a pig or other vertebrate (as a cat, rat, or rabbit), where it encysts itself in the muscles of its hosts. In the case of pork, if the meat is eaten in an uncooked condition, the cyst is dissolved off by the action of the digestive fluids, and the living trichina becomes free in the intestine of man. Here it bores its way through the intestine walls and enters the muscles, causing inflammation there. This causes a painful and often fatal disease known as trichinosis.

The Hookworm. — The discovery by Dr. C. W. Stiles of the

Bureau of Animal Industry, that the laziness and shiftlessness of the "poor whites" of the South is partly due to a parasite called the hookworm, another roundworm, reads like a fairy tale.

The people, largely farmers, become infected with a larval stage of the hookworm, which develops in moist earth. It enters the body usually through the skin of the feet, for children and adults alike, in certain localities where the disease is common, go barefoot to a considerable extent.

A complicated journey from the skin to the intestine now fol-

A family of poor whites, all of whom are infected with hookworm disease.

lows, the larvæ passing through the veins to the heart, from there to the lungs; here they bore into the air passages and eventually reach the intestine by way of the windpipe. One result of the injury of the lungs is that many thus infected are subject to tuberculosis. The adult worms, once in the food tube, fasten themselves and feed upon the blood of their host by puncturing the intestine wall. The loss of blood from this cause is not sufficient to account for the bloodlessness of the person infected, but it has been discovered that the hookworm pours out a poison into the wound which pre-

vents the blood from coagulating (see page 367) rapidly; hence a considerable loss of blood occurs from the wound after the worm has finished its meal and gone to another part of the intestine.

The cure of the disease is very easy; thymol, which weakens the hold of the worm, being followed by Epsom salts. For years the entire South undoubtedly has been retarded in its development by this parasite, and hundreds of millions of dollars and, what is more vital, thousands of lives, have been needlessly sacrificed.

"The hookworm is not a bit spectacular: it doesn't get itself discussed in legislative halls or furiously debated in political campaigns. Modest and unassuming, it does not aspire to such dignity. It is satisfied simply with (1) lowering the working efficiency and the pleasure of living in something like two hundred thousand persons in Georgia and all other Southern states in proportion; with (2) amassing a death rate higher than tuberculosis, pneumonia, or typhoid fever; with (3) stubbornly and quite effectually retarding the agricultural and industrial development of the section; with (4) nullifying the benefit of thousands of dollars spent upon education; with (5) costing the South, in the course of a few decades, several hundred millions of dollars. More serious and closer at hand than the tariff; more costly, threatening, and tangible than the Negro problem; making the menace of the boll weevil laughable in comparison — it is preëminently the problem of the South." — *Atlanta Constitution.*

Parasitic worms are of vital importance to mankind. Not only do they levy a tax of death and illness on man himself, but they destroy as well unestimated millions of dollars' worth of animals. Of the 2,000,000 persons infected with hookworm, 500,000 are wage earners (and this is a small estimate); their earnings at $1.50 a day would amount to about $225,000,000 a year. If their wage-earning capacity were decreased only 10 per cent, it is seen that a loss of over $20,000,000 a year could be directly attributed to this pest.

Other Parasitic Worms. — Some roundworm parasites live in the skin, and others live in the intestines of the horse. Still others are parasitic in fish and in insects, one of the commonest being the hair snake, often seen in country brooks.

Classification of Segmented Worms (Annulata)

Class I. *Chætopoda* (bristle-footed). Segmented worms having setæ.
Subclass I. *Polychæta* (many bristles). Having parapodia and usually head and gills. Example: sandworm.
Subclass II. *Oligochæta* (few bristles). No parapodia, head, or gills. Example: earthworm.
Class II. *Discophora* (bearing suckers). No bristles, two sucking disks present. Example: leech.

Platyhelminthes (Flatworms)

Body flattened in dorso-ventral direction.

Class I. *Turbellaria*. Small, aquatic, mostly not parasitic. Example: planarian worm.
Class II. *Trematoda*. Usually parasitic worms which have complicated life history. Example: liver fluke of sheep.
Class III. *Cestoda*. Internal parasites having two hosts. Example: tapeworm.

Nemathelminthes (Roundworms)

Threadlike worms, mostly parasitic. Examples: vinegar eel, *Trichina*, and hookworm.

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XVIII. THE CRAYFISH. A STUDY OF ADAPTATIONS

Problem XXIX. *A study of the idea of adaptations as shown in the crayfish (optional). (Laboratory Manual, Prob. XXIX.)*

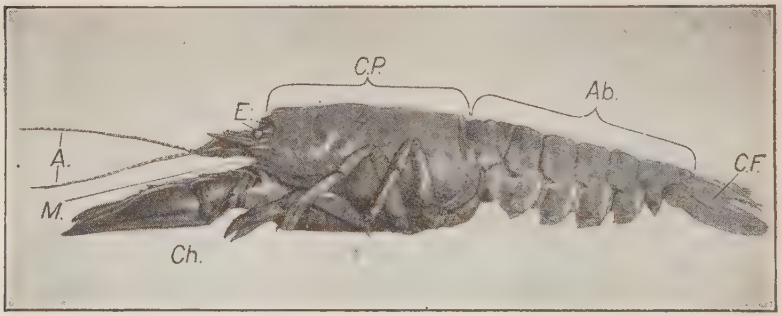
(*a*) *Protection.*
(*b*) *Locomotion.*
(*c*) *Surroundings.*
(*d*) *Feeding.*
(*e*) *Breathing.*

Adaptations. — Plants and animals are in a continual struggle to hold the places they have obtained upon the earth. Continually we see garden plants driven out or killed by the competing weeds, simply because the weeds are better fitted or *adapted* to live under the conditions which exist in the garden, especially if it is uncultivated. An adaptation in a plant or animal is some structure, habit, or ability which is of advantage to the organism in its battle for life. We have seen many examples of adaptations in plants, — adaptations in flowers for securing cross-pollination, in fruits for seed-scattering, in young plants for protection, in roots for water-securing; the list is endless.

In animals, likewise, the successful competitors are the ones with adaptations to fit them for living in the particular environment or surroundings in which nature has put them. Examples are often seen where animals, like sheep or goats, which have a woolly covering, when introduced by man into a warmer country, die because the outer coat is too warm. An adaptation for withstanding cold becomes harmful to the animal under conditions of greater heat.

One adaptation which we have already noticed in animals is always protective. This is resemblance of the animal to the surroundings in which it lives. Other adaptations aid the animal in obtaining and digesting food, in protecting itself or its young from attack by enemies, and in many other ways aiding the animal to battle successfully with the dangers around it.

The Crayfish. Adaptations for Protection. — An animal which well illustrates adaptation for life in the water is the fresh-water crayfish or the salt-water lobster, both members of a large group of animals known as *crustaceans*. The body of such an animal is seen to be covered more or less completely with a hard covering, which is jointed in the posterior region. This *exoskeleton* (outside skeleton) is composed largely of lime, as may be proved by testing with acid. The exoskeleton fits over the anterior part of the animal, forming an unjointed *carapace*, or armor. This armor is clearly protective and is thus an adaptation. If the crayfish is watched in a balanced aquarium, the colors, too, are seen to blend remarkably with the stones and water weeds of the bottom. The animal is protectively colored. The under side of the animal is seen to be less well pro-



Crayfish: A., antennæ; *E.*, stalked eye; *C.P.*, cephalothorax; *Ab.*, abdomen; *C.F.*, caudal fin; *M.*, mouth; *Ch.*, chelipeds. From photograph.

tected than the upper, and the joints of the *abdomen*, or posterior region, are seen to extend completely around the body. The animal is thus seen to be *segmented*, the abdomen showing this plainly. The seven segments in the abdomen are constant for every crayfish.

Locomotion. — Those of us who have caught crayfish in fresh-water streams or lakes know that it takes skill and quickness. They dart backwards through the water with great rapidity, or they may move forward by crawling on the bottom. Examination of a crayfish shows us five pairs of walking legs attached to the under side of the *cephalothorax* (head + thorax), the anterior part of the body. These legs are jointed, the first three bearing pinchers. The large pincher claw is used partly for food-catching, and for locomotion as well. Try to find out, in a living specimen, exactly what part it plays.

Under the abdomen, one to each segment except the last, are found jointed appendages, made up of three parts, a base and two branches. These are called *swimmerets*, though they are *not* used for swimming. Now look at the broad pair of appendages that, together with the last

segment of the abdomen, form a finlike apparatus, the *caudal fin*. The caudal fin is composed of two large swimmerets and the last body segment. Crayfish normally swim very rapidly by means of a sudden jerking in a backward direction of the caudal fin. The abdomen is provided with powerful muscles which are attached to the exoskeleton. It is by these muscles that the rapid swimming is accomplished.

Female lobster, showing eggs attached to the swimmerets. From photograph loaned by the American Museum of Natural History.

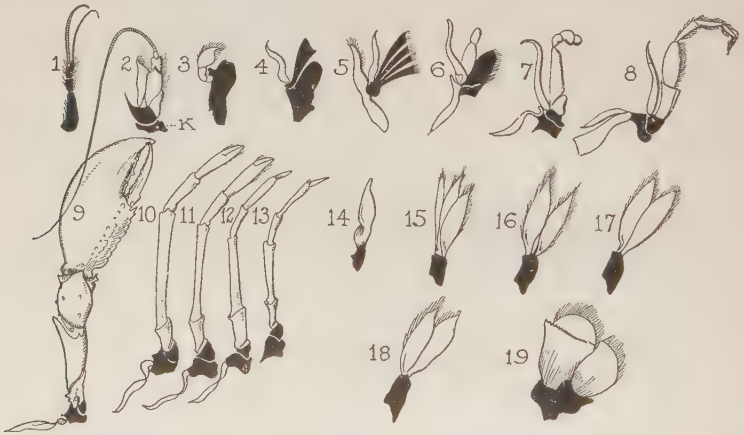
How the Crayfish gets in Touch with its Surroundings. — Several other appendages besides those used for locomotion are found. Two pairs of "feelers," the longer pair called the *antennæ*, the shorter the *antennules* (little antennæ), protrude from the front of the body. The longer feelers appear to be used as organs of touch. Certain hairlike structures projecting from the antennæ have to do with the sense of smell. The smaller antennules hold at their bases little sacs called "ears." These "ears" have largely to do with the function of balancing rather than hearing.

Just above the antennules, projecting on stalks, are the eyes. These eyes are made up of many small structures called *ommatidia*, each of which is a very simple eye. A collection of ommatidia is known as a *compound eye*. A little bit of the outer covering of the eye, mounted under a compound microscope, shows these eye units to be shaped like tiny rectangles in cross section. Such an eye probably does not have very distinct vision at a distance. A crayfish, however, easily distinguishes moving objects and prefers darkness to light, as may be proved by experiment.

Feeding. — If it is possible to have the aquarium holding the crayfish in the schoolroom, the method of feeding may be watched. The pincher claws (*chelipeds*) are used to hold and tear food, as well as for defense and offense. Living food is obtained with the aid of the chelipeds. Food is shoved by the chelipeds toward the mouth; it is assisted there by three pairs of small appendages called foot jaws (*maxillipeds*), and to a

slight degree by two still smaller paired *maxillæ* just under the maxillipeds. Ultimately the food reaches the hard *jaws* and, after being ground between them, is passed down to the stomach.

Breathing. — The mouth parts of a crayfish resting in the aquarium are observed to be constantly in motion, despite the fact that no food is present. If a crayfish is taken out of the water and held with the ventral surface upmost, a little carmine (dissolved in water) may be dropped on the lower surface and allowed to run down under the carapace. If now the animal is held in water in the same position, the carmine will reappear just beyond from both sides of the mouth, seemingly propelled by something which causes it to emerge in little puffs. If we



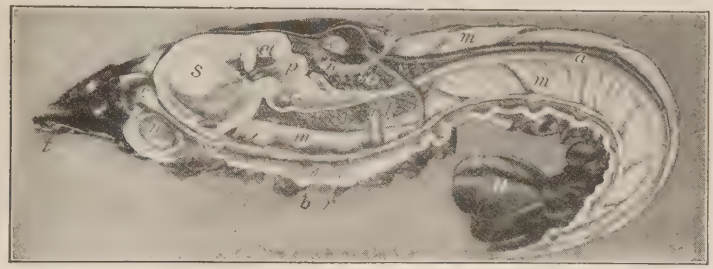
Appendages of the crayfish: *1*, antennule; *2*, antenna; *3*, mandible; *4*, first maxilla; *5*, second maxilla; *6*, first maxilliped; *7*, second maxilliped; *8*, third maxilliped; *9*, forceps; *10*, walking leg; *11*, walking leg, genital opening in female; *12*, walking leg; *13*, walking leg, genital opening in male; *14*, modified swimmeret in male; *15*, modified swimmeret in male; *16*, *17*, *18*, swimmerets, in female carry the eggs; *19*, uropod.

remove the maxillipeds and maxillæ from a dead specimen, we find a groove leading back from each side of the mouth to a cavity of considerable size on each side of the body under the carapace. This is the *gill* chamber. It contains the *gills*, the organs which take oxygen out of the water. The second maxillæ are prolonged down into the groove to serve as bailers or scoops. By rapid action of this organ a current of water is maintained which passes over the gills.

The gills are outside of the body, although protected by the carapace. If the carapace is partly removed on one side, they will be found looking somewhat like white feathers. The blood of the crayfish passes by a series of vessels into the long axis of the gill; in this organ the blood tubes divide into very minute tubes, the walls of which are extremely

delicate. Oxygen, dissolved in the water, passes into the blood by osmosis, during which process the blood loses some carbon dioxide. The gills are kept from drying by being placed in a nearly closed chamber, which is further adapted to its function by means of the row of tiny hairs which border the lower edge of the carapace. Thus crayfish may live for long periods away from water.

Circulation. — The circulation of blood in the crayfish takes place in a system of thin-walled, flabby vessels which are open in places, allowing the blood to come in direct contact with the tissues to which it flows. The heart lies on the dorsal side of the body, inclosed in a delicate bag, into which all the blood in the body eventually finds its way during its circulation.



Crayfish with the left half of the body structures removed: *a*, intestines; *b*, ventral artery; *c*, brain; *e*, heart; *et*, gastric teeth; *i*, oviduct; *l*, digestive gland; *m*, muscles; *n*, green gland (kidney); *o*, ovary; *p*, pyloric stomach; *r*, nerve cords; *s*, cardiac stomach; *st*, mouth; *u*, telson; *w*, openings of veins into the pericardial sinus. Natural size. (Davison, *Zoölogy.*)

Digestion. — Food which is not ground up into pieces small enough for the purpose of digestion is still further masticated by means of three teeth, strong projections, one placed on the mid-line and two on the side walls of the stomach. The exoskeleton of the crayfish extends down into the stomach, thus forming the *gastric mill* just described.

The stomach is divided into anterior and posterior parts separated from each other by a constriction. The posterior part is lined with tiny projections from the wall which make it act as a strainer for the food passing through. Thus the larger particles of food are kept in the anterior end of the stomach. Opening into the posterior end of the stomach are two large digestive glands which further prepare the food for absorption through the walls of the intestine. Once in the blood, the fluid food is circulated through the body to the tissues which need it.

Nervous System. — The internal nervous system of a crayfish consists of a series of collections of nerve cells (*ganglia*) connected by means of a double line of nerves. Posterior to the gullet, this chain of ganglia is found on the ventral side of the body, near the body wall. It then en-

circles the gullet and forms a brain in the head region, the latter formed from several ganglia which have grown together. From each of the ganglia, nerves pass off to the sense organs and into the muscles of the body. These nerve fibers are of two sorts, those bearing messages from the outside of the body to the central nervous system (these messages result in sensations), and those which take outgoing messages from the central nervous system (motor impulses), which result in muscular movements.

Development. — The sexes in the crayfish are distinct. The eggs are fertilized by the sperm cells as they pass to the outside of the body of the female. The developing eggs, which are provided with a considerable supply of food material called yolk, are glued fast to the swimmerets of the mother, and there develop in safety. The young, when they first hatch, remain clinging to the swimmerets for several weeks.

Excretion of Wastes. — On the basal joint of the antennæ are found two projections, in the center of which are found tiny holes. These are the openings of the *green glands*, organs which have the function of the elimination of nitrogenous waste from the blood, the function of the human kidneys.

North American lobster. This specimen, preserved at the U.S. Fish Commission at Woods Hole, was of unusual size and weighed over twenty pounds. Notice the chelipeds.

The North American Lobster. — In structure it is almost the counterpart of its smaller cousin, the crayfish. Its geographical range is a strip of ocean bottom along our coast, estimated to vary from thirty to fifty miles in width. This strip extends from Labrador on the north to Delaware on the south. The lobster is highly sensitive to changes in temperature. It migrates from deep to shallow water, or *vice versa*, according to the temperature of the water, which in winter is relatively warmer in deep water and cooler in shallows. Sudden changes in the water of a given locality may cause them to disappear from that place. The more abundant food supply near the shore also aids in determining the habitat of the lobster. Lobsters do not appear to migrate north and south along the coast. While little is known about

their habits on the ocean bottom, it is thought that they construct burrows somewhat like the crayfish, in which they pass part of the time. As they have the color of the bottom and as they pass much of their time among the weed-covered rocks, they are able to catch much living food, even active fishes falling prey to their formidable pinchers. They move around freely at night, usually remaining quiet during the day, especially when in shallow water. They eat some dead food; and thus, like the crayfish, they are scavengers.

Development. — The female lobsters begin to lay eggs when about seven inches in length. Lobsters of this size lay in the neighborhood of five thousand eggs; this number is increased to about ten thousand in lobsters of moderate size (ten inches in length); in exceptionally large specimens as many as one hundred thousand eggs are sometimes laid. The eggs are laid every alternate year, usually during the months of July and August. Eggs laid in July or August, as shown by observations made along the coast of Massachusetts, hatch the following May or June. The eggs are provided with a large supply of yolk (food), the development of the young animal taking place at the expense of this food material. After the young escape from the egg, they are almost transparent and little like the adult in form. During this period of their lives the mortality is very great, as they are the prey of many fish and other free-swimming animals. It is estimated that barely one in five thousand survives this period of peril. At this time they grow rapidly, and in consequence are obliged to shed their exoskeleton (molt) frequently. During the first six weeks of life, when they swim freely at the surface of the water, they molt from five to six times.[1]

Metamorphosis of a shrimp: *a*, nauplius or earliest stage; *b*, *c*, *d*, later larval stages; *e*, adult. Note that as the animal grows more appendages appear, and that these develop backward from the anterior end.

[1] Recent economic investigations upon the care of the young developing lobster show that animals protected during the first few months of free existence have

Molting. — During the first year of its life the lobster molts from fourteen to seventeen times. During this period it attains a length of from two to three inches. Molting is accomplished in the following manner: The carapace is raised up from the posterior end and the body then withdrawn through the opening between it and the abdomen. The most wonderful part of the process is the withdrawal of the flesh of the large claws through the very small openings which connect the limbs with the body. The blood is first withdrawn from the appendage; this leaves the flesh in a flabby condition (a state similar to the taproot which has lost water by osmosis) so that the muscles can be drawn through without injury. The lobster also molts a part of the lining of the digestive tract as far as the posterior portion of the stomach. Immediately after molting the lobster is in a helpless condition, and is more or less at the mercy of its enemies until the new shell, which is secreted by the skin, has grown.

Economic Importance. — The lobster is highly esteemed as food, and is rapidly disappearing from our coasts as the result of overfishing. Between twenty million and thirty million are yearly taken on the North Atlantic coast. This means a value at present prices of about $15,000,000. Laws have been enacted in New York and other states against overfishing. Egg-carrying lobsters must be returned to the water; all smaller than six to ten and one half inches in length (the law varies in different states) must be put back; other restrictions are placed upon the taking of the animals, in hope of saving the race from extinction. Some states now hatch and care for the young for a period of time; the United States Bureau of Fisheries is also doing much good work, in hope of restocking to some extent the now almost depleted waters.

Shrimps. — Several other common crustaceans are near relatives of the crayfish. Among them are the shrimps and prawns, thin-shelled, active crustaceans common along our eastern coast. In spite of the fact that they form a large part of the food supply of many marine animals, especially fishes, they do not appear to be decreasing in numbers. Be-

a far better chance of becoming adults than those left to grow up without protection. Later in life they sink to the bottom, and because of their protectively colored shell and the habit of hiding under rocks and in burrows, they are comparatively safe from the attack of enemies.

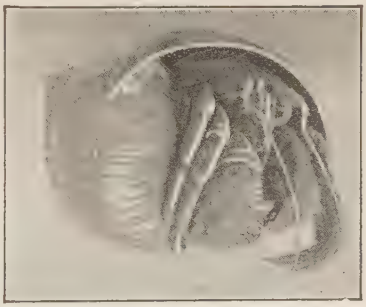
sides this value as a food, they are also used by man, the shrimp fisheries in this country aggregating over $1,000,000 yearly.

The Blue Crab. — Another edible crustacean of considerable economic importance is the blue crab. Crabs are found inhabiting muddy bottoms; in such localities they are caught in great numbers in nets or traps baited with decaying meat. They are, indeed, among our most valuable sea scavengers, although they are carnivorous hunters as well. The body of the crab is short and broad, being flattened dorso-ventrally. The abdomen is much reduced in size. Usually it is carried close to the under surface of the cephalothorax; in the female the eggs are carried under its ventral surface, fastened to the rudimentary swimmerets in the position which is usual for other crustaceans. The young crabs differ considerably in form from the adult. They undergo a complete *metamorphosis* (change of form), and their method of life differs from the adult. Immediately after molting, crabs are greatly desired by man as an article of food. They are then known as "shedders," or soft-shelled crabs.

The edible blue crab. From photograph loaned by the American Museum of Natural History.

Other Crabs. — Other crabs seen along the New York coast are the prettily colored lady crabs, often seen running along our sandy beaches at low tide; the fiddler crabs, interesting because of their burrows and gregarious habits; and perhaps most interesting of all, the hermit crabs.

The fiddler crab. From photograph loaned by the American Museum of Natural History.



Hermit crab, about twice natural size. From photograph loaned by the American Museum of Natural History.

The hermit crabs use the shells of snails as homes. The abdomen is soft, and unprotected by a limy exoskeleton, and has adapted itself to its con-

ditions by curling around in the spiral snail shell, so that it has become asymmetrical. These tiny crabs are great fighters and wage frequent duels with each other for possession of the more desirable shells. They exchange their borrowed shells for larger ones as growth forces them from their first homes.

The habits of these animals, and those of the fiddler crabs, might be studied with profit by some careful boy or girl who spends a summer at the seashore and has the time and inclination to devote to the work. Of especial interest would be a study of the food and feeding habits of the fiddler crabs.

A deep-water crab often seen along Long Island Sound is the spider crab, or "sea spider," as it is incorrectly called by fishermen. This animal, with its long spider-like legs, is neither an active runner nor swimmer; it is, however, colored like the dark mud and stones over which it crawls; thus it is enabled to approach its prey without being noticed. The resemblance to the bottom is further heightened by the rough body covering, which gives a hold for seaweeds and sometimes sessile animals, as barnacles, hydroids, or sea anemones, to fasten themselves.

Giant spider crab from Japan. From photograph loaned by the American Museum of Natural History.

A spider crab from the Sea of Japan is said to be the largest crustacean in the world, specimens measuring eighteen feet from tip to tip of the first pair of legs having been found.

Symbiosis. — Certain of the spider crabs, as well as some of the larger deep-water hermit crabs, have come to live in a relation of mutual helpfulness with hydroids, sponges, and sea anemones. These animals attach themselves to the shell of the crab and are carried around by it, thus receiving a constant change of position and a supply of food. What they do for the crab in return is not so evident, although one large Chinese hermit regularly plants a sea anemone on its big claw; when forced to retreat into its shell, the entrance is thus effectually blocked by the anemone. The

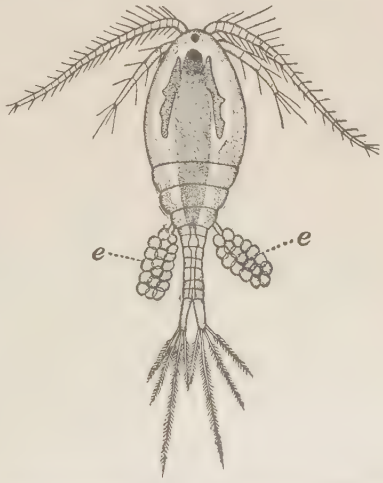
living of animals in a mutually helpful relation has been referred to as *symbiosis*. Of this we have already had some examples in plants as well as among animals. (See page 187.)

Habitat. — Most crustaceans are adapted to live in the water; a few forms, however, are found living on land. Such are the wood lice, the pill bugs, which have the habit of rolling up into a ball to escape attack of enemies, the beach fleas, and others. The coconut crab of the tropics climbs trees in search of food, returning to the water at intervals to moisten the gills.

Characters of Crayfish and its Allies. — Our study of crayfish shows us that animals belonging to the same group as itself have several well-marked characteristics. The most important are the presence of a segmented limy exoskeleton, gills, jointed appendages, usually a pair to each segment of the body (except the last), stalked compound eyes, and the fact that they pass through a *metamorphosis* or change of form before they reach the adult state.

We find that the Crustacea fall naturally into two classes, those in which the number of pairs of appendages varies, and those in which the number is fixed at nineteen. In this latter class are placed the crayfish, lobster, blue crab, shrimp, and most of our common crustaceans.

Entomostraca. — Another subclass of crustaceans, in which the number of appendages varies, is the group *Entomostraca*. They are mostly small animals, some species existing in countless numbers. One of the largest Entomostracans inhabiting fresh water is the fairy shrimp (*branchippus*) found appearing in early spring in fresh-water ponds, a little translucent swimming animal from one half to three fourths of an inch in length. Another fresh-water form often seen in aquaria is the water flea (*daphnia*). From the economic standpoint, probably the most important crustaceans that we shall study are the copepods. These tiny



Cyclops (note the single eye-spot). This is a very common copepod and is magnified about forty times. *e*, egg masses.

animals are barely visible to the naked eye. They are found in almost every part of the world, from the arctic seas to those of the tropics, and in fresh as well as salt water. They are so numerous that the sea in places is colored by their bodies. So prolific are they that it is estimated that one copepod may produce in a single year four billion five hundred million offspring. These animals form a large part of the food supply of many of our most important food fishes as well as the food of many other aquatic animals. The whale, for example, subsists largely on this kind of food. They are, then, in an indirect way, of immense economic value.

Degenerate Crustaceans. — One of the most interesting forms to a zoölogist is the goose barnacle. This crustacean, like all others of the group, is free-swimming during its early life. Later, however, after passing through several changes in form during its development, the barnacle settles down on a rock or some floating object, fastens itself along the dorsal surface, and remains fastened during the rest of its life. Food comes to it in a current of water, which is set in motion by the rhythmical beating of the appendages. Thus food particles are carried along the ventral side of the body to the mouth. Such animals, having lost the power of locomotion, are said to be *degenerate*.

Parasitic Crustaceans. — Other crustaceans have become even more helpless and have come to take their living from other animals. In some cases they become simply a bag for absorbing nourishment from the host on which they are fastened. Such is the *sacculina*, a degenerate crustacean that lives attached to the body of the crab. Others attach themselves to fishes and are known to fishermen as fish lice.

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XIX. THE INSECTS

Problem XXX. *A study of some animal likenesses and differences, and the classification of insects (optional). (Laboratory Manual, Prob. XXX.)*

(a) Grasshopper — a straight-winged insect.
(b) Butterfly or moth — a scale-winged insect.
(c) The typhoid fly — a two-winged insect.
(d) A beetle — a sheath-winged insect.
(e) A bug — a half-winged insect.
(f) The dragon fly — a nerve-winged insect.
(g) The bee — a membrane-winged insect.
(h) Summary of differences between orders.
(i) Making a logical definition.

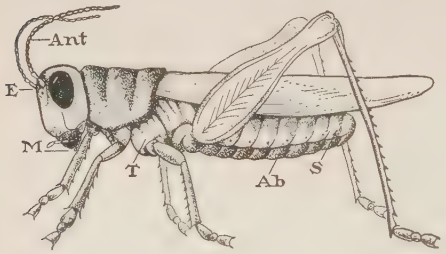
Insects the Winners in Life's Race. — We are all familiar with common examples of insect life. Bees and butterflies we have already studied in connection with their work in the cross-pollination of flowers. Mosquitoes and flies all too often come to our notice as pests; the common household insects sometimes annoy us, while we often hear and see in a small way the harm done by insects in the field and garden. Insects are a successful group. They outnumber all the other species of animals on the face of the earth. They hold their own in the air, in the water, and on land. Fitted in many ways to lead the successful life, they have become winners in life's race.

We have already, from our study of a bee, formed some idea of what an insect is. But it would be unfair to expect to know *all* insects from our slight knowledge of one form. Our object in the study of this chapter will be to get some first-hand knowledge of some common insects so that we may classify them and distinguish one from another. This great group, containing more than half of the known representatives of animal life on the earth, is made up of a number of groups called *orders*. The insects contained in these orders have certain characters of structure and

life history in common, yet each differs somewhat from the other orders. The characters which *all* the groups contain in common give us a working definition of an insect.

One of the most common insects in the United States is the locust or grasshopper, as it is commonly called. The study of a living specimen (or if it cannot be obtained, a dead locust) will, better than any other insect, give us insight into the structure and life processes of this great group.

The Locust (Red-legged Grasshopper). — The segmented body is divided into a *head*, a middle portion (the *thorax*), and a posterior part, the *abdomen*. The legs, six in number, and two pairs of wings are attached to the thorax. The animal lives a rather active life in the fields, the hind pair of legs being adapted by shape, position, and in structure for leaping. Careful examination of the foot of the animal shows a number of tiny hooks and pads, by means of which the foot is fitted for clinging to the swaying grass stalks.



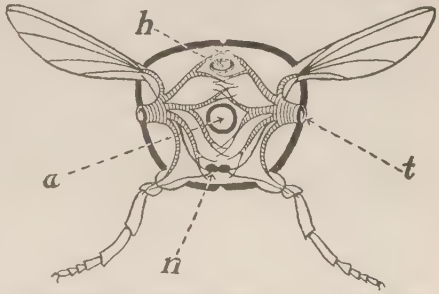
Red-legged grasshopper (*Melanoplus femur-rubrum*): *Ab*, abdomen; *Ant*, antennæ; *E*, eye; *M*, mouth; *T*, thorax; *S*, spiracles.

Wings. — The membranelike wings, when spread out, show differences in structure. Notice the many veins. The outer pair, strong and narrower than the inner pair, serve to protect the inner wings, used for flying, which when at rest fold up like a fan. The animal, when in its natural habitat, is nearly the color of the grass on which it lives. The tough exoskeleton covering the body is formed largely of chitin, a substance somewhat like that which forms the horns of a cow.

Thorax. — Three segments form the thorax, each bearing a pair of jointed legs, the two posterior segments bearing wings also.

The Abdomen. — The segmented abdomen does not bear appendages, but at the posterior end of the abdomen of the female are found paired movable pieces which together form the egg layer or *ovipositor*. The male grasshopper has a rounded abdomen.

Breathing Organs. — Observation of the abdomen of a living grasshopper shows a frequent movement of the abdomen. Along the side of the abdomen in eight of the segments (in the red-legged grasshopper) are found tiny openings called *spiracles*. A large spiracle may easily be found in the middle segment of the thorax. These spiracles open into little tubes called *tracheæ*. The tracheæ carry air to all parts of the body. By the movements of the abdomen just noted, air is drawn into and forced out of the tracheæ. The tracheæ divide and subdivide like branches of a tree, so that all the body cavity is reached by their fine endings. Some even pass outward into the veins of the wings. Each of these tubes contains air. The blood of an insect does not circulate through a system of closed blood tubes as in man, but instead it more or less completely fills that part of the body cavity which is not filled with other organs. Oxygen is thus brought in contact with the blood by means of the tracheæ.



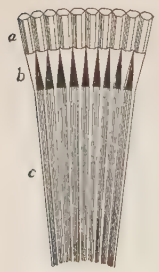
Cross section through the body of an insect: *a*, food tube; *h*, heart; *n*, nerve cord; *t*, tracheæ opening at *t* by spiracle.

Muscular Activity. — Insects have the most powerful muscles of any animals of their size. Relatively, an enormous amount of energy is released during the jumping or flying of a grasshopper. The tracheæ pass directly into the muscles and other tissues. Here oxygen is passed into the tissues, and oxidation takes place when work is done.

Food-Taking and Blood-Making. — The grasshopper is provided with two pairs of jaws, a forklike ventral-lying pair, the *maxillæ*, and a pair of hard cutting jaws, the *mandibles*. These parts are covered when not in use by two flaps, the upper and lower lips. The plant food taken by the grasshopper is held in place in the mouth by means of the little jaws, or the maxillæ, while it is cut into small pieces by the mandibles. Just behind the mouth is a large crop into which empty the contents of the salivary glands. It is this fluid mixed with digested food that we call the "grasshopper's molasses." After the food is digested by the action of the

saliva and other juices, it passes in a fluid state through the walls of the intestine, where it becomes part of the blood. As blood it is passed on to tissues, such as muscle, to make new material to be used in repairing that which is used up during the flight of the insect or to be oxidized to release energy for the active insect.

Eyes. — A considerable part of the surface of the head of the grasshopper is taken up by the compound eyes. Examination with a lens shows the whole surface to be composed of tiny hexagonal spaces called *facets*. Each facet is believed to be a single eye, with perhaps distinct vision from its neighbor. The grasshopper also has three simple eyes on the front of the head. The simple eyes probably are only able to perceive light and darkness. The separate units of the compound eye probably each give a separate impression of light and color. Thus a compound eye is most favorable for perceiving the movement of objects.



Longitudinal section of part of the compound eye of an insect: *a*, facets; *c*, nerves.

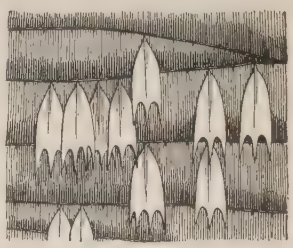
Other Sense Organs. — The segmented feelers, or *antennæ*, have to do with the sense of touch and smell. The eardrum, or *tympanum*, of the grasshopper is found under the wing on the first segment of the abdomen. Covering the body and on the appendages, are found hairs (sensory hairs) which appear to make the insect sensitive to touch. Thus the armor-covered animal is put in touch with its surroundings.

Nervous System. — The nerve chain, as in the crayfish, is on the ventral side of the body. As in the crayfish, it passes around the gullet near the head to the dorsal side, where a collection of ganglia forms the brain. Nerves leave the central system as outgoing fibers which bear *motor* impulses. Other nerve fibers pass inward, and produce sensations. These are called *sensory* fibers.

Life History. — The female red-legged locust lays its eggs by digging a hole in the ground with her ovipositor, or egg-layer, the modified end of the abdomen. From twenty to thirty eggs are laid in the fall; these hatch out in the spring as tiny wingless grasshoppers, otherwise like the adult. As in the crayfish, the young molt in order to grow larger, each grasshopper undergoing several molts before reaching the adult state. No great change in form occurs, the metamorphosis being said to be incomplete. In the fall most of the adults die, only a few surviving the winter.

Relatives of the Locust. — Among the near relatives are the brown or black crickets, cockroaches and "waterbugs," the katydid,

praying mantis, and many others. All of the above insects have the hind wings, when present, folded up lengthwise against the body when at rest, mouth parts fitted for biting, and an incomplete metamorphosis. They are thus placed in an order called *Orthoptera* because the posterior wings are folded straight against the body when at rest (*orthos*, straight, *pteron*, wing).



Part of the wing of a moth (*samia*), magnified to show the arrangement of scales partly rubbed off.

The Butterfly. — The body of the butterfly, as that of the grasshopper, is composed of three regions. Compared with the grasshopper, the wings and legs show the greatest differences in structure. The legs of the butterfly are relatively smaller and weaker than those of the grasshopper, while the wings are relatively larger in the first-named insect. Evidently the butterfly spends much of its time in the air.

Monarch butterfly: adults, larva, and pupa on milkweed. From photograph loaned by the American Museum of Natural History.

If the wing is rubbed with the finger, dust comes off it, leaving the wing transparent or membrane-like. Under the microscope the wing is seen to be covered with thousands of little colored scales, each of which fits into a socket in the wing. These scales cause the name *Lepidoptera* (*lepis*, scale, *pteron*, wing) to

be given to this order of insects. The long proboscis, a sucking tube through which the insect sucks nectar from flowers, is another character by which the *Lepidoptera* may be known.

Life History. — The monarch or milkweed butterfly (*Anosia plexippus*) is one of our commonest insects. Its orange-brown, black-veined wings are familiar to every boy or girl who has been outdoors in the country during the fall months. The adult female lays her eggs in the late spring on the milkweed. The eggs, tiny sugar-loaf-shaped dots a twentieth of an inch in length, are fastened singly to the underside of milkweed leaves. Some wonderful instinct leads the animal to deposit the eggs on the milkweed, for the young feed upon no other plant. Eggs laid in May hatch out in four or five days into rapid-growing caterpillars, each of which will molt several times before it becomes full size. These caterpillars possess in addition to the three pairs of true legs, additional pairs of *prolegs* or caterpillar legs. The animal at this stage is known as a *larva*.

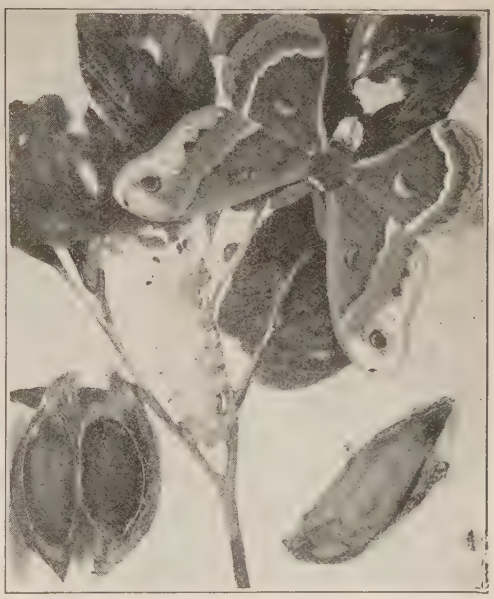
Formation of Pupa. — After a life of a few weeks at most, the caterpillar stops eating and begins to spin a tiny mat of silk upon a leaf or stem. It attaches itself to this web by the posterior pair of prolegs, and there hangs until a last molt (which occurs within twenty-four hours after attachment) gives the animal the form it assumes in the stage known as the *chrysalis* or *pupa*.

The Adult. — After a week or more of inactivity, the exoskeleton is split along the dorsal side, and the adult butterfly emerges. At first the wings are soft and much smaller than in the adult. Within fifteen minutes to half an hour after the butterfly emerges, however, the wings are full-sized, having been pumped full of blood.

In the adult form the animal may survive the winter. The milkweed butterfly is a strong flyer, and has been found over five hundred miles at sea. They may migrate southward upon the approach of the cold weather. Some common forms, as the mourning cloak (*Vanessa antiopa*), hibernate in the North, passing the cold weather under stones or overhanging clods of earth.

Comparison between a Moth and a Butterfly. - The big electric light moth cecropia (*Samia cecropia*) is an insect familiar to most of us. In general it resembles a butterfly in structure. Several differences, however, occur. The body is much stouter than that of the butterfly. The wings

and body appear to have a thicker coating of hairs and scales, and the antennæ are feathery. The position of the wings when at rest forms another easy way of distinguishing the one insect from the other. (See Figures, page 237).



Life history of the cecropia moth. Above, the adult; the larva (caterpillar) in center; the pupal case to right, below; the same cut open at left, below. From photograph loaned by the American Museum of Natural History.

Development. The Egg. — The eggs, cream-colored and as large as a pinhead, are deposited in small clusters on the underside of leaves of the food plant. The young are at first tiny black caterpillars, which later change color to a bluish green, with projections of blue, yellow, and red along the dorsal side.

The Pupal Stage. — Unlike the butterfly, the moth passes the quiescent stage in a case of silk or other material called a cocoon. The cocoons of cecropia may be found in the fall on willows or alders. Such cocoons found in meadows or fields are usually larger than those found on the hillsides, probably because of a difference in the food supply of the larva which spun the cocoon.

If the cocoon is cut open lengthwise (see Figure), the dormant insect or chrysalis will be found together with the cast-off skin of the caterpillar which spun the case.

Polyphemus, one half natural size. Photographed by Davison.

Silkworms. — The American silkworm (*Telea polyphemus*) is another well-known moth. The cocoons, made in part out of the leaves of the elm, oak, or maple, fall to the ground when the leaves drop, and hence are

not so easily found as those of the cecropia. This moth is a near relative of the Chinese silkworm, and its silk might be used with success were it not for the high rate of labor in this country. The Chinese silkworm is now raised with ease in southern California. China, Japan, Italy, and France, because of cheap labor, are still the most successful silk-raising countries.

Differences Between Moths and Butterflies

Butterfly	Moth
Antennæ threadlike, usually knobbed at tip.	Antennæ feathery or threadlike, never knobbed.
Fly in daytime.	Usually fly at night.
Wings held vertically when at rest.	Wings held horizontally or folded over the body when at rest.
Pupa naked.	Pupa usually covered by a cocoon.

Moths and butterflies are both characterized by having a sucking proboscis, membranous wings covered with scales, and both undergo a complicated metamorphosis or change of form. By these characters we know them to be members of the order *Lepidoptera.*

Diptera. The Typhoid Fly. — This name has been recently given to the common house fly by L. O. Howard, the Chief of the Bureau of Entomology, United States Department of Agriculture.

Life history of house flies, showing from left to right the eggs, larvæ, pupæ, and adult flies. Photograph, about natural size, by Overton.

We shall later see with what reason this name is given. The body of the fly, as in other insects, has three divisions. The membranous wings appear to be two in number, a second pair being reduced

to tiny knobbed hairs called balancers. Their function is seemingly that of equilibrium.

The head is freely movable, the compound eyes being extremely large. Seemingly the fly has fairly acute vision. Home experiments can be easily made which prove its keenness of scent and taste. It is well equipped to care for itself in its artificial environment in the house.

The mouth parts of the fly are prolonged to form a proboscis, which is tonguelike, the animal obtaining its food by lapping and sucking. It is the rubbing of this file-like organ over the surface of the skin that causes the painful bite of the horsefly.

If possible, we should examine the foot of a fly under the compound microscope. The foot shows a wonderful adaptation for clinging to smooth surfaces. Two or three pads, each of which bears tubelike hairs that secrete a sticky fluid, are found on its under surface. It is by this means that the fly is able to walk upside down. Hooks are also present which doubtless aid in locomotion in this position.

Foot of a fly, showing the hooks, hairs, and pads.

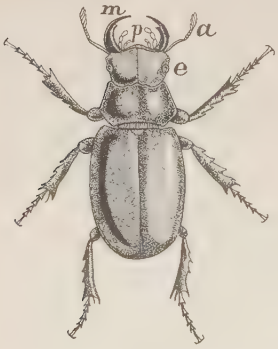
Development. — The development of the typhoid fly is extremely rapid. A female may lay from one hundred to two hundred eggs. These are usually deposited in filth or manure. Dung heaps about stables, ash heaps, garbage cans, and fermenting vegetable refuse form the best breeding places for flies. In warm weather, within a day after the eggs are laid, the young maggots, as the larvæ are called, hatch. After about one week of active feeding, these wormlike maggots become quiet and go into the pupal stage, whence under favorable conditions they emerge within less than another week as adult flies. The adults breed at once, and in a short summer there may be over ten generations of flies. This accounts for the great number. Fortunately few flies survive the winter.

Other Diptera. — Other examples of this group are the mosquitoes, of which more will be said hereafter; the Hessian fly, the

larvæ of which feed on young wheat; the botfly, which in a larval state is a parasite on horses; the dreaded tsetse fly of South Africa, which causes disease in horses and cattle by means of the transference of a parasitic protozoan, much like that which causes malaria in man; and many others.

Among the few flies useful to man may be mentioned the tachina flies, the larvæ of which feed on the cutworm, the army worm, and various other kinds of injurious caterpillars.

Characters of the Diptera. — Members of this group have only one pair of wings; the mouth parts are fitted for sucking, rasping, or piercing, and they pass through a complete metamorphosis.



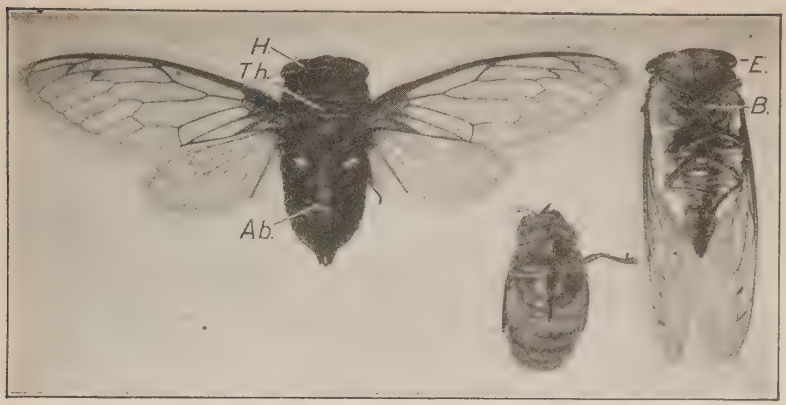
Stag beetle: *a*, antenna; *e*, eye; *m*, mandible; *p*, palpus. Drawing one half natural size.

Coleoptera. Beetles. — Beetles are the most widely distributed and among the most numerous of all insects. There are over one hundred thousand living species.

Any beetle will show the following characteristics: (1) The body is usually heavy and broad. Its exoskeleton is hard and tough, the chitinous body covering being better developed in the beetles than in any other of the insects. (2) The three pairs of legs are stout and rather short. (3) The outer wings are hard and fit over the under wings like a shield. These sheathlike wings are called *elytra*. (4) The mouth parts, provided with an upper and lower lip, are fitted for biting. They consist of very heavy curved pincher-shaped mandibles, which are provided with palps.

The Life History of a Beetle. — The June beetle (May beetle) and potato beetle are excellent examples. May beetles lay their eggs in the ground, where they hatch into cream-colored grubs. A grub differs from the larva fly or maggot in possessing three pairs of legs. These grubs live in burrows in the ground. Here they feed on the roots of grass and garden plants. The larval form remains underground for from two to three years, the latter part of this time as an inactive pupa. During the latter stage it lies dormant in an ovoid area excavated by it. Eventually the wings (which are budlike in the pupa) grow larger, and the adult beetle emerges fitted for its life in the open air.

Order Hemiptera. Bugs. Characteristics. — The cicada, or, as it is incorrectly called, the locust, is a familiar insect to all. Its droning song is one of the accompaniments of a hot day. The song of the cicada is



Cicada: *1*, adult with wings spread, showing abdomen (*Ab.*), head (*H.*), thorax (*Th.*); *2*, pupal case, showing the split down the back; *3*, ventral view, showing beak (*B.*), eye (*E.*).

produced by a drumlike organ which can be found just behind the last pair of legs. The sound is caused by a rapid vibration of the tightly stretched drumhead. The body is heavy and bulky. The wings, four in number, are relatively small, but the powerful muscles give them very rapid movement. The anterior wings are larger than the posterior. The legs are not large nor strong, the movement when crawling being sluggish. One of the characteristics of the cicada, and of all other bugs, is that the mouth parts are prolonged into a beak with which the animal first makes a hole and then sucks up the juices of the plants on which it lives.

Life History. — The seventeen-year cicada lays her eggs in twigs of trees, and in doing this causes the death of the twig. The young leave the tree immediately after hatching, burrow underground, and pass from thirteen to seventeen years there, depending upon the species of cicada. In the South this period is shortened. They live by sucking the juices from roots. During this stage they somewhat resemble the grub of the beetle (June bug) in habits and appearance. When they are about to molt into an adult, they climb aboveground, cling to the bark of trees, and then crawl out of the skin as adults.

Maple scale, five adults and many young. From photograph, enlarged twice, by Davison.

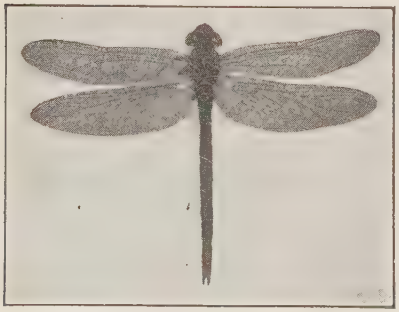
Aphids. — The aphids are among the most interesting of the bugs. They are familiar to all

as the tiny green lice seen swarming on the stems and leaves of the rose and other cultivated plants. They suck the juices from stem and leaf. Plant lice have a remarkable life history. Early in the year eggs develop into wingless females, which produce living young, all females. These in turn reproduce in a similar manner, until the plant on which they live becomes overcrowded and the food supply runs short. Then a generation of winged aphids is produced. These fly away to other plants, and reproduction goes on as before until the approach of cold weather, when males and females appear. Fertilized eggs are then produced which give rise to young the following season.

The aphids exude from the surface of the body a sweet fluid called honeydew. This is given off in such abundance that it is estimated if an aphid were the size of a cow, it would give two thousand quarts a day. This honeydew is greatly esteemed by other insects, especially the ants. For the purpose of obtaining it, some ants care for the aphids, even providing food and shelter for them. In return the aphid, stimulated by a stroking movement of the antenna of the ant, gives up the honeydew to its protector.

The Order Neuroptera

The Dragon Fly. — The dragon fly receives its name because it preys on insects. It eats, when an adult, mosquitoes and other insects which it captures while on the wing. Its four large lacelike wings give it power of very rapid flight, while its long narrow body is admirably adapted for the same purpose. The large compound eyes placed at the sides of the head give keen sight. It possesses powerful jaws (almost covered by the upper and lower lips).



Dragon fly. Notice the long abdomen and large compound eyes.

The long, thin abdomen does not contain a sting, contrary to the belief of most children. These insects deposit their eggs in the water, and the fact that they may be often seen with the end of the abdomen curved down under the surface of the water in the act of depositing the eggs has given rise to the belief that they were then engaged in stinging something. The egg hatches into a form of larva called a *nymph*, which in the dragon fly is characterized by a greatly developed lower lip. When the animal is at rest, the lower lip covers the large biting jaws, which can be extended so as to grasp and hold its prey. The nymphs of the dragon fly take oxygen out of the water by means of gill-like structures placed in the posterior

part of the food tube. They may live as larvæ from one summer to as long as two years in the water. They then crawl out on a stick, molt by splitting the skin down the back, and come out as adults.

A nearly related form is the damsel fly. This may be distinguished from the dragon fly by the fact that when at rest the wings are carried close to the abdomen, while in the dragon fly they are held in a horizontal position.

May Flies. — Another near relative of the dragon fly is the May fly. These insects in the adult stage have lost the power to take food. Most of their life is passed in the larval stage in the water. The adults sometimes live only a few hours, just long enough to mate and deposit their eggs.

The Order Hymenoptera

We have already learned something of the structure of the bee, an example of this order. Other relatives are the wasps, ichneumons (wasp-like insects with long ovipositors), and the ants. The structural characters of this group are the presence of two pairs of membranous wings, the mouth parts being fitted for biting and lapping. All undergo a complete metamorphosis, the young being helpless wingless creatures somewhat like the maggots of the fly. Of this group we shall learn more later.

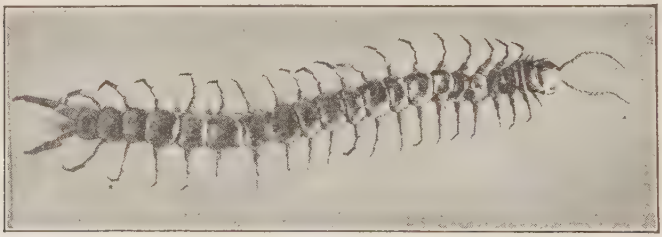
The orders of insects mentioned above are only some examples of this very large group. In all of the above forms we have seen certain likenesses and certain differences in structure, but all of the above have had three body divisions, three pairs of legs, and have possessed in the adult state air tubes called tracheæ. These are the principal characters by which we may identify the insects.

Spiders and Myriapods. — Spiders are not true insects, although they are nearly allied to them. The body shows the same division as do the higher crustaceans, cephalothorax and abdomen; *four* pairs of walking legs mark another difference. These animals usually have four pairs of simple eyes and breathe by means of lunglike sacs in the abdomen, the openings of which can sometimes be seen just behind the most posterior pair of legs. Another organ possessed by the spider, which insects do not have (except in a larval

Tarantula on its back: *p*, poison fang; *s*, spinneret. Reduced from photograph by Davison.

form), is known as the *spinneret*. This is a set of glands which secrete in a liquid state the silk which the spider spins. On exposure to air, this fluid hardens and forms a very tough building material which combines lightness with strength.

Uses and Form of the Web. — The web-making instinct of spiders forms an interesting study. Our common spiders may be grouped according to the kind of web they spin. The web in some cases is used as a home; in others it forms a snare or trap. In some cases the web is used for ballooning, spiders having been noticed clinging to their webs miles out at sea. The webs seen most frequently are the so-called cobwebs. These usually serve as a snare rather than a home, some species remaining away from the web. Other webs are funnel-shaped, still others are of geometrical exactness, while one form of spider makes its home underground, lines the hole with silk, and makes a trapdoor which can be closed after the spider has retreated to its lair.



A poisonous centipede from Texas. Half natural size. From photograph by Davison.

Myriapods. — We are all familiar with the harmless and common thousand legs found under stones and logs. It is a representative of the group of animals known as the millepedes. These animals have the body divided into two regions, head and trunk, and have two pairs of legs for each body segment. The centipedes, on the other hand, have only one pair of legs to each segment. Both are representatives of the class *Myriapoda*. None of the forms in the eastern part of the United States are poisonous.

Insects and Crustaceans Compared. — Both crustaceans and insects belong to a great group of animals which agree in that they have jointed appendages and bodies, and that they possess an exoskeleton. This group or phylum is known as the *Arthropoda*. Spiders and myriapods are also included in this group.

Insects differ structurally from crustaceans in having three regions in the body instead of two. The number of legs (three

pairs) is definite in the insects; in the crustaceans the number sometimes varies (as in the Entomostraca), but is always more than three pairs. The exoskeleton, composed wholly of chitin in the insects, is usually strengthened with lime in the crustaceans. Both groups have compound eyes, but those of the Crustacea are staked and movable. The other sense organs do not differ greatly. The most marked differences are physiological. The crustaceans take in oxygen from the water by means of gills, while the insects are air breathers, using for this purpose air tubes called *tracheæ*.

The young of both insects and crustaceans usually undergo several changes in form before the adult stage is reached. They are thus said to pass through a *metamorphosis*. Both insects and crustaceans, because of their exoskeleton, must molt in order to increase in bulk.

Classification of Arthropoda

Phylum Arthropoda

Class, *Crustacea*. Arthropods with limy and chitinous exoskeleton, rarely more than 20 body segments, usually breathing by gills, and having two pairs of antennæ.

Subclass I. *Entomostraca*. Crustacea with a variable number of segments, chiefly small forms with simple appendages. Some degenerate or parasitic. Examples: barnacles, water flea (*Daphnia*), and copepod (*Cyclops*).

Subclass II. *Malacostraca*. Usually large Crustacea having nineteen pairs of appendages. Examples: American lobster (*Homarus Americanus*), crab (*Cancer*), and shrimp (*Palæmonetes*).

Class, *Hexapoda* (insects). Arthropoda having chitinous exoskeleton, breathing by air tubes (*tracheæ*), and having three distinct body regions.

Order, Aptera (without wings). Several wingless forms. Examples: springtails.

Order, Orthoptera (straight wings). Example: Rocky Mountain locust.

Order, Lepidoptera (scale wings). Examples: cabbage butterfly, cecropia moth.

Order, Diptera (two wings). Examples: fly, mosquito.

Order, Hemiptera (half wing). Examples: all true bugs, plant lice, and cicada.

Order, Neuroptera (nerve wings). Examples: May fly, dragon fly.

Order, Coleoptera (shield wings). Examples: beetles.

Order, Hymenoptera (membrane wings). Examples: bees, wasps, ants.

Class, *Arachnida*. Arthropoda with head and thorax fused. Six pairs of appendages. No antennæ. Breathing by both lung sacs (spiders) or tracheæ. Examples: spiders and scorpions.

Class, *Myriapoda*. Arthropoda, having long bodies with many segments; one or two pairs of appendages to each segment. Breathing by means of tracheæ. Example: centipede.

An exercise for field work with a simple key for identification of orders will be found in the Labratory Manual, Prob. XXX.

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XX. GENERAL CONSIDERATIONS FROM THE STUDY OF INSECTS

Problem XXXI. *How insects became winners in life's race.* (*Laboratory Manual, Prob. XXXI.*)

(*a*) *Protective resemblance.*
(*b*) *Aggressive resemblance.*
(*c*) *Mimicry.*
(*d*) *Communal life.*
(*e*) *Symbiosis.*
(*f*) *Parasitism.*

Insects are by far the most numerous of all animals. It is estimated that there are more species of insects than of all other species of animals upon the globe. Why should insects come to have existed in so much greater numbers than other animals? We cannot explain this, but some light is thrown on the problem when we consider some of the ways in which insects have become winners in life's race.

The walking stick on a twig, showing protective resemblance.

Protective Resemblance. — When we remember that the chief enemies of insects are birds and other animals which use them as food, we can see that the insect's power of rapid flight must have been of considerable importance in escaping from enemies. But other means of pro-

tection are seen when we examine insects in their native haunts. We have noted that various animals, such as the earthworm and crayfish, escape observation because they have the color of their surroundings. Insects give many interesting examples of protective coloration or protective resemblance. The grasshopper is colored like the grass on which it lives. The katydid, with its green body and wings, can scarcely be distinguished from the leaves on which it rests. The walking stick, which resembles the twigs on which it is found, and the walking-leaf insect of the tropics, are other examples.

The underwing moth; above, flying; below, at rest on bark.

One example frequently quoted is the dead-leaf butterfly of India. This insect at rest resembles a dead leaf attached to a limb; in flight, because of its vivid colors, it is conspicuous. The underwing moth is another example of a wonderful simulation of the background of bark on which the animal rests in the daytime. At night the brightly colored underwings probably give a signal to others of the same species. The beautiful luna moth, in color a delicate green, rests by day among the leaves of the hickory. The small measuring worms stand out stiff upon the branches on which they crawl, thus simulating lateral twigs. Hundreds of other examples might be given.

This likeness of an animal to its immediate surroundings has already been noted as *protective resemblance.*

Aggressive Resemblance. — Sometimes animals which resemble their surroundings are thus better able to catch their prey. The polar bear is a notable example. Some insects are thus colored. The mantis, shown in the figure, has strongly built forelegs, with which it seizes and holds insects on which it preys. The mantis

has the color of its immediate surroundings, and is thus enabled to seize its prey before the latter is aware of its presence. Many other examples could be given.

Mantis, showing aggressive resemblance.

Warning Coloration and Protective Mimicry. — Some insects are extremely unpleasant, both to smell or to taste, while others are provided with means of defense such as poison hairs or stings. Such animals are almost always brightly colored or marked as if to warn animals to keep off or take the consequences. Examples of insects which show warning by color may be seen in many examples of beetles, especially the spotted ladybirds, potato beetles, and the like. Wasps show yellow bands, while many forms of caterpillars are conspicuously marked or colored.

Some insects, especially caterpillars, are brightly colored and protrude horns, or pretend to sting when threatened with attack. These animals evidently mimic animals which really are protected by a sting or by poison, although this mimicry is not voluntary on the part of the insect. One of the best-known cases of insect mimicry is seen in the case of the imitation of the monarch butterfly by the viceroy.

Monarch and viceroy butterflies: the latter (at the right) is a mimic.

The monarch butterfly (*Anosia plexippus*) is an example of a race which has received protection from enemies in the struggle for life, because of its nauseous taste and, perhaps, because its caterpillar feeds on plants of no commercial value.

Another butterfly, less favored by nature, resembles the monarch in outward appearance. This is the viceroy (*Basilarchia archippus*). It seems probable that in the early history of the species called viceroy some of this edible form escaped from the birds because they resembled in color and form the species of inedible monarchs. These favored individuals produced new butterflies which resembled the monarch more closely. So for generation after generation the ones which were most like the inedible species were left, the others becoming the food of birds. Ultimately a species of butterflies was formed that owed its existence to the fact that it resembled another more favored species. In this way nature selects the animals which can exist upon the earth. Many other examples of mimicry may be found among insects; one of the easiest to find is the locust borer, shown in the Figure. Some flies imitate bees, and thus escape capture.

Hornet mimicked by locust borer, a beetle.

The chief insect enemies are the birds, and from these the most effective protection seems to be hairs on the body. Few birds eat hairy caterpillars of any species; fortunately, however, the hairy larvæ of the gypsy moth, a serious pest, are eaten by no less than thirty-one species of birds. The odors or ill flavors of insects seem to be generally protective, but stinging insects do not appear to be protected from all birds, flycatchers and swallows habitually feeding on the bees and wasps.[1]

Communal Life among Insects. — Insects are of especial interest to man because among certain species a system of social life has arisen comparable to that which exists among men. In connection with this communal life, nature has worked out a division of labor which is very remarkable. This can be seen in tracing out the lives of several of the insects which live in communities.

[1] See Judd, J. S., "The Efficiency of Some Protective Adaptations in securing Insects from Birds," *American Naturalist*, Vol. 33, pages 461–484.

Solitary Wasps. — Some bees and wasps lead a solitary existence. The solitary and digger wasps do not live in communities. Each female constructs a burrow in which she lays eggs and rears her young. The young are fed upon spiders and insects previously caught and then stung into insensibility. The nest is closed up after food is supplied, and the young later gnaw their way out. In the life history of such an insect there is no communal life.

Bumblebee. — In the life history of the big bumblebee we see the beginning of the community instinct. Some of the female bees (known as *queens*) survive the winter and lay their eggs the following spring in a mass of pollen, which has been previously gathered and placed in a hole in the ground. The young hatch as larvæ, then pupate, and finally become workers, or females. In the working bee the egg-laying apparatus, or ovipositor, is modified to be used as a sting. The workers bring in pollen to the queen, in which she lays more eggs. Several broods of workers are thus hatched during a summer. In the early fall a brood of males or drones, and egg-laying females or queens, are produced instead of workers. By means of these egg-producing females the brood is started the following year.

The Honeybee. — The most wonderful communal life is seen among the honeybees.[1]

The honeybee in a wild state makes its home in a hollow tree; hence the term "bee tree." In the hive the colony usually consists of a queen, or egg-laying female, a few hundred drones, or males, and several thousand working females, or workers. The colonies vary greatly in numbers, in a wild state there being fewer in the colony. The division of labor is well seen in a hive in which the bees have been living for some weeks. The queen does nothing except lay eggs, sometimes laying three thousand eggs a day and keeping this up, during the warm weather, for several years. She may lay one million eggs during her life. She does not, as is popularly believed, rule the hive, but is on the contrary a captive most of her life. Most of the eggs are fertilized by the sperm cells of the males; the unfertilized eggs develop into males or drones.

[1] Their daily life may be easily watched in the schoolroom, by means of one of the many good and cheap observation hives now made to be placed in a window frame. Directions for making a small observation hive for school work can be found in Hodge, *Nature Study and Life*, Chap. XIV. Bulletin No. 1, U.S. Department of Agriculture, entitled *The Honey Bee*, by Frank Benton, is valuable for the amateur beekeeper. It may be obtained for twenty-five cents from the Superintendent of Documents, Union Building, Washington, D.C.

After a short existence in the hive the drones are usually driven out by the workers. The fertilized eggs may develop into workers, but if the young larva is fed with a certain kind of food, it will develop into a young queen.

Hornets' nest, open to show the cells of the comb. Photograph by Overton.

The cells of the comb are built by the workers out of wax secreted from the under surface of the bodies. The wax is cut off in thin plates by means of the wax shears between the two last joints of the hind legs. These cells are used by the queen to place her eggs in, one to each cell, and the young are hatched after three days, to begin life as footless white grubs.

For a few days they are fed on partly digested food called bee jelly, regurgitated from the stomach of the workers. Later they receive pollen and honey to eat. A little of this mixture, known as bee

Honeybees: *a*, drone; *b*, worker; *c*, queen. Photograph by Davison.

bread, is then put into the cell, the lid covered with wax by the working bees, and the young larvæ allowed to pupate. After

about two weeks of quiescence in the pupal state, the adult worker breaks out of the cell and takes her place in the hive, first caring for the young as a nurse, later making excursions to the open air after food as an adult worker.

If new queens are to be produced, several of the cell walls are broken down by the workers, making a large ovoid cell in which one egg develops. The young bee in this cell is fed during its whole larval life upon bee jelly, and grows to a much larger size than an ordinary worker. When a young queen appears, great excitement pervades the community; the bees appear to take sides; some remain with the young queen in the hive, while others follow the old queen out into the world. Here they usually settle around the queen, often hanging to the limb of a tree. This is called swarming. This instinct is of vital importance to the bees, as it provides them with a means of forming a new colony. For while the bees are swarming, certain of the workers, acting as scouts, determine on a site for their new home; and, if undisturbed, the bees soon go there and construct their new hive. A swarm of domesticated bees, however, may be quickly hived in new quarters.

We have already seen (pages 42 and 43) that the honeybee gathers nectar, which she swallows, keeping the fluid in her crop until her return to the hive. Here it is regurgitated into cells of the comb. It is now thinner than what we call honey. To thicken it, the bees swarm over the open cells, moving their wings very rapidly, thus evaporating some of the water in the honey. A hive of bees have been known to make over thirty-one pounds of honey in a single day, although the average record is very much less than this.

Ants.— Ants are the most truly communal of all the insects. Their life history and habits are not so well known as those of the bee, but what is known shows even more wonderful specialization. The inhabitants of a nest may consist of wingless workers, which in some cases may be of two kinds, and winged males and females.

Ant larvæ are called grubs. They are absolutely helpless and are taken care of by nurses. The pupæ may often be seen taken out in the mouths of the nurse ants for sun and air. They are mistakenly called ants' eggs in this stage

The colonies consist of underground galleries with enlarged storerooms, nurseries, etc. The ants are especially fond of honeydew secreted

by the aphids, or plant lice. Some species of ants provide elaborate stables for the aphids, commonly called ants' cows, supplying with food and shelter and taking the honeydew as their reward. This they obtain by licking it from the body of the aphids. A Western form of ant, found in New Mexico and Arizona, rears a scale insect on the roots of the cactus for this same purpose.

Diagram of an artificial ants' nest: *S*, moistened sponge. (After Miss Fielde.)[1]

It is probable that some species of ants are among the most warlike of any insects. In the case of the robber ants, which live entirely by war and pillage, the workers have become modified in structure, and can no longer work, but only fight. Some species go further and make slaves of the ants preyed upon. These slaves do all the work for their captors, even to making additions to their nest and acting as nurses to their young.

Ants and their "cows," the aphids.

The entire communal life of the ants seems to be based upon the perception of odor. If an ant of the same species but from a different

[1] A successful nest for the schoolroom is made and described by Miss Adele M. Fielde. See the *Biological Bulletin*, Vol. VII, No. 4, September, 1904.

The floor of the nest is a pane of window glass six by ten inches. Build a wall by cementing with crockery cement four half-inch strips of thicker glass, and upon these cement four more strips, making the wall at least one quarter of an inch high. The space inside is divided by one or two partitions built the same as the outer wall. Spaces should be allowed for communication between chambers. The whole outer surface of the nest thus made may be covered with black paper to make it opaque. A lining of Turkish toweling is glued to the top of the wall. The cover, which rests on the toweling, should be either of glass made opaque, or better, of glass (such as ruby glass of dark rooms) that will exclude most of the ultra-violet light rays. It is best to provide a separate roof for each chamber. Ants need moisture, so that a small bit of moist sponge should be kept in the room where the ants live. The food chamber, where bits of cake, banana, apple, or other food mixed with honey or molasses, are placed, should also be kept moist.

To stock such a nest, dig up a small colony and transfer them, along with some earth, to the schoolroom. To separate the ants from the earth, place them with the earth on a little island of wood in a basin of water. On one side of the island place a glass plate, and shade this plate by a piece of opaque paper raised slightly above the glass. The ants soon remove themselves and their young to the dark area, and may then be transferred to the nest. Ant colonies have been kept for three or four years in such a nest.

nest be put into another colony, it will be set upon and either driven out or killed. Ants never really lose their community odor; those absent for a long time, on returning, will be easily distinguished by their odor, and eagerly welcomed by the members of the nest. The talking of ants (when they stop each other, when away from the nest, to communicate) is evidently a process of smelling, for they caress each other with the antennæ, the organs with which odors are perceived.

Symbiosis. — We have already seen that plants and animals frequently live in a state of partnership or relation of mutual help. Such a state is known as a *symbiotic* relation. The keeping of the aphids by the ants which use them as "cows" is an example of this relation among two species of insects. The ants provide protection and sometimes food; the aphids give up the honeydew of which the ants are so fond.

But a wider symbiotic relation exists directly between the flowering plants and the insects. We all know the very great service done the plants by the pollination of the flower by the insects, and we know that the return is the supply of pollen and nectar as food for the insects. If it were not for the bees, wasps, and butterflies, it is safe to predict that many of our fruit crops would be almost entire failures. Do you know why?

Parasitism. — One of the near relatives of the bee called the ichneumon fly does man indirectly considerable good because of its habit of laying its eggs and rearing the young in the bodies of caterpillars which are harmful to vegetation. Some of the ichneumons even bore into trees in order to deposit their eggs in the larvæ of wood-boring insects. It is safe to say that by the above means the ichneumons save millions of dollars yearly to this country.

Thalessa boring in an ash tree to deposit its eggs in the burrow of a horntail larva, a wood borer. From photograph, natural size, by Davison.

Unfortunately, not all insect parasites do good. Animals of all kinds, but especially birds, are infested with lice and fleas. The ticks are well known for the harm they do, while the larvæ of the botflies which live in the bodies of various mammals, as the horse and sheep and cattle, are insect parasites which do much harm.

Problem XXXII. *Some relations of insects to man.* (*Laboratory Manual, Prob. XXXII.*)

(*a*) *With reference to disease.*

(*b*) *With reference to destruction of property.*

(*c*) *With reference to benefit to man.*

The Relation of Insects to Mankind. — We already have seen this relation is twofold, harmful or beneficial. The harmful relation may affect man directly, as when human disease is carried by insects, or it may be indirect, as in the case of damage to crops, trees, stored food, or clothing. The first relation, naturally of more importance, as malaria and typhoid fever, two extremely prevalent diseases, may be largely due to insects. There are probably one million cases of "chills and fever" in the Southern states alone every year. Malaria and typhoid could be largely eradicated if there were no mosquitoes or flies. It is therefore evident that a careful study of the habits of these insects is worth our while.

The Malarial Mosquito. — Fortunately for mankind, not all mosquitoes harbor the small one-celled parasite (a protozoan) which causes malaria. The harmless mosquito (*culex*) may be usually distinguished from the mosquito which carries malaria (*anopheles*) by the position taken when at rest. (See page 197.) Culex lays eggs in tiny rafts of one hundred or more eggs in any standing water; thus the eggs are distinguished from the eggs of anopheles, which are not in rafts. Rain barrels, gutters, or old cans may breed in a short time enough mosquitoes to stock a neighborhood. The larvæ are known as wigglers. They breathe through a tube in the posterior end of the body, and may be recognized by their peculiar movement when on their way to the surface to breathe. The fact that both larvæ and pupæ take air from the surface of the water makes it possible to kill the mosquito

during these stages by pouring oil on the surface of the water where they breed. The introduction of minnows, gold fish, or other small fish which feed upon the larvæ in the water where the mosquitoes breed will do much in freeing a neighborhood from this pest. Draining swamps or low land which holds water after a rain is another method of extermination.

Since the beginning of historical times, malaria has been prevalent in regions infested by mosquitoes. The ancient city of Rome was so greatly troubled by periodic outbreaks of malarial fever that a goddess of fever came to be worshiped in order to lessen the severity of what the inhabitants believed to be a divine

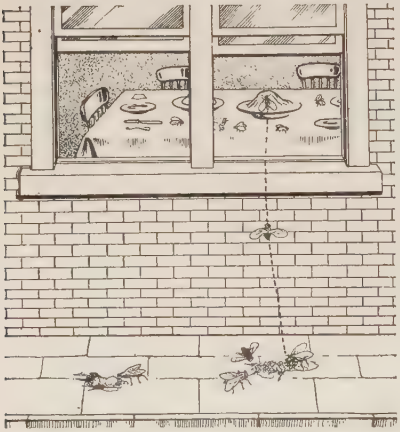
Three pupæ and two larvæ of mosquitoes at the surface of the water, breathing. The black line is the water surface. Photograph from life, twice natural size, by Davison.

visitation. At the present time the malaria of Italy is being successfully fought and conquered by the draining of the mosquito-breeding marshes. By a little carefully directed oiling of water a few boys may make an almost uninhabitable region absolutely safe to live in. Why not try it if there are mosquitoes in your neighborhood ?

Yellow Fever and Mosquitoes. — Another disease which has been proved to be carried by mosquitoes is yellow fever. In the year 1878 there were 125,000 cases and 12,000 deaths in the city of Memphis, Tenn., alone, with thousands of deaths in other Southern cities. During the French occupation of the Panama Canal zone the work was at a standstill part of the time because of the ravages of yellow fever.

But to-day this is changed, and yellow fever is under almost complete control, both here and wherever the mosquito (*stegomyia*) which carries yellow fever exists. The mosquitoes are prevented from biting persons having yellow fever; for in this way only can the disease be spread. Drainage and oiling of breeding places, and screening of all windows, are helping to build the Panama Canal.

The Typhoid Fly a Pest. — The common fly is recognized as a pest the world over. Flies have long been known to spoil food through their filthy habits, but it is more recently that the very serious charge of spread of diseases, caused by bacteria, has been laid at their door. In a recent experiment two young men from the Connecticut Agricultural Station found that a single fly might carry anywhere from 500 to 6,600,000 bacteria, the average number being over 1,200,000. Not all of these germs are harmful, but they might easily include those of typhoid fever, tuberculosis, summer complaint, and possibly other diseases. A recent pamphlet published by the Merchants' Association in New York city shows that the rapid increase of flies during the summer months has a definite correlation with the increase in the number of cases of summer complaint. Observations in other cities seem to show the increase in number of typhoid cases in the early fall is due, in part at least, to the same cause. It has been estimated that the loss caused from this disease is in a single year $350,000,000 in the United States alone. A large part of this loss is indirectly due to the typhoid fly.



Showing how flies may spread disease by means of contaminating food.

Other Diseases due to Insects. — The bubonic plague, the dreaded scourge of the East, is probably carried to man by fleas. The sleeping sickness of Africa has already been mentioned (page 197)

as carried by the tsetse fly. Several other diseases of man and many other animals, especially cattle, are carried by flies. The Texas fever of cattle is carried by a cattle tick, an animal closely allied to the insects.

When flies are plentiful, there is a considerable increase in the number of cases of illness among babies.

Economic Loss from Insects. — The money value of crops, forest trees, stored foods, and other material destroyed annually by insects is beyond belief. It is estimated that they get one tenth of the country's crops, at the lowest estimate a matter of some $300,000,000 yearly.

"A recent estimate by experts put the yearly loss from forest insect depredations at not less than $100,000,000. The common schools of the country cost in 1902 the sum of $235,000,000, and all higher institutions of learning cost less than $50,000,000, making the total cost of education in the United States considerably less than the farmers lost from insect ravages.

"Furthermore, the yearly losses from insect ravages aggregate nearly twice as much as it costs to maintain our army and navy; more than twice the loss by fire; twice the capital invested in manufacturing agricultural implements; and nearly three times the estimated value of the products of all the fruit orchards, vineyards, and small fruit farms in the country." — *Slingerland.*

In 1874–1876 the damage to crops by the Rocky Mountain locust has been estimated at $200,000,000. At certain times, these locusts migrate from Colorado, Wyoming, and Dakota, where they seem always to be found, and descend in countless millions upon the grain fields to the eastward. Fortunately, these invasions have been rare in recent years. The total value of all farm and forest

crops, excluding animal products, in New York, is perhaps $150,000,000, and the one tenth that the insects get is worth $15,000,000. It may seem incredible that it costs such a sum to feed New York's injurious insects every year, but it is an average of $66 for each of the 227,000 farms in the state; and there are few farms where the crops are not lessened more than this amount by insects.

Insects which damage Garden and other Crops. — The grasshoppers have been mentioned as among the most destructive of these. The larvæ of various moths do considerable harm here, especially the "cabbage worm," the various caterpillars of the hawk moths which feed on grape and tomato vines, the cutworm, a feeder on all kinds of garden truck, the corn worm, a pest on corn, cotton, tomatoes, peas, and beans. The last annually damages the cotton crop to the amount of several millions of dollars.

Among the beetles which are found in gardens is the potato beetle, which destroys the potato plant. This beetle formerly lived in Colorado upon a wild plant of the same family as the potato, and came east upon the introduction of the potato into Colorado, evidently preferring cultivated forms to wild forms of this family. The asparagus and cucumber beetles are also often in evidence.

Cotton-boll weevil: *a*, larva; *b*, pupa; *c*, adult. Photograph, enlarged four times, by Davison.

The one beetle doing by far the greatest harm in this country is the cotton-boll weevil. Imported from Mexico, since 1892 it has spread over eastern Texas and into Louisiana. The beetle lays its eggs in the young cotton fruit or boll, the larvæ feeding upon the substance within the boll. It is estimated that if unchecked this pest would destroy yearly one half of the cotton crop, a matter

of $250,000,000. Fortunately, the United States Department of Agriculture are at work on the problem, and, while they have not found any way of exterminating the beetle as yet, it has been found that, by planting more hardy varieties of cotton, the crop matures earlier and ripens before the weevils have increased in sufficient numbers to destroy the crop (see page 62).

The bugs are among our most destructive insects. The most familiar examples of our garden pests are the squash bug; the chinch bug, which yearly does damage estimated at $20,000,000, by sucking the juice from the leaves of grain; and the plant lice, or aphids.

Some aphids are extremely destructive to vegetation. One, the grape Phylloxera, yearly destroys immense numbers of vines in the vineyards of France, Germany, and California.

The Hessian fly, the larvæ of which live on the wheat plant, was introduced accidentally by the Hessians in their straw bedding during the Revolution, and has become one of our most serious insect pests.

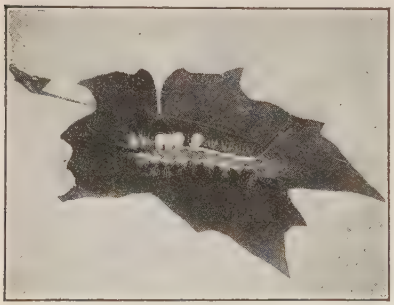
Insects which harm Fruit and Forest Trees. — Great damage is done annually by the larvæ of moths. Massachusetts has already spent over $3,000,000 in trying to exterminate the imported gypsy moth. The codling moth, which bores into apples and pears, is estimated to ruin yearly $3,000,000 worth of fruit in New York alone, which is by no means the most important apple region of the United States. Among these pests, the most important to the dweller in a large city is the tussock moth, which destroys our shade trees. The caterpillar may easily be recognized by its hairy, tufted red head. The eggs are laid on the bark of shade trees in what look like masses of foam. (See Figure.) By collecting and burning the egg masses in the fall, we may save many shade trees the following year.

Female tussock moth which has just emerged from the cocoon at the left, upon which it has deposited over two hundred eggs. Photograph, slightly enlarged, by Davison.

Other enemies of the shade trees are the fall webworm, the forest

caterpillar, and the tent caterpillar; the last spins a tent which serves as a shelter in wet weather.

The larvæ of some moths damage the trees by boring into the wood of the tree on which they live. Such are the peach, apple, and other fruit-tree borers common in our orchards. Some species of beetles produce boring larvæ which eat their way into trees and then feed upon the sap of the tree. Many trees in our Adirondack Forest Reserve annually succumb to these pests. Many trees are killed because the beetle girdles the tree, cutting through the tubes in the cambium region. Most fallen logs will repay a search for the larvæ which bore between the bark and wood.



Larva of tussock moth. Photograph, natural size, by Davison.

Among the bugs most destructive to trees are the scale insect and the plant lice, or aphids. The San José scale, a native of China, was introduced into the fruit groves of California about 1870 and has spread all over the country. It lives upon numerous plants, and is one of the worst pests this country has seen. It is interesting to know that a ladybird beetle, which has also been imported, is the most effective agent in keeping this pest in check.

Insects of the House or Storehouse. — The weevils are the greatest pests, frequently ruining tons of stored corn, wheat, and other cereals. Roaches feed on almost any kind of breadstuffs as well as on clothing. The carpet beetle is a recognized foe of the housekeeper, the larvæ feeding upon all sorts of woolen material. The larvæ of the clothes moth do an immense amount of damage to stored clothing especially. Fleas, lice, and especially bedbugs are among man's personal foes.[1]

Beneficial Insects. — Fortunately for mankind, many insects are found which are of use because they either prey upon injurious

[1] Directions for the treatment of these pests may be found in pamphlets issued by the U.S. Department of Agriculture.

insects or become parasites upon them, eventually destroying them. The ichneumon flies are examples already mentioned. They undoubtedly do much in keeping down the number of destructive caterpillars.

Several beetles are of value to man. Most important of these is the natural enemy of the orange-tree scale, the ladybug, or ladybird beetle. In New York state it may often be found feeding upon the plant lice, or aphids, which live on rosebushes. The carrion beetles and many water beetles act as scavengers. The sexton beetles bury dead carcasses of animals. Ants in tropical countries are particularly useful as scavengers.

Insects, besides pollinating flowers, often do a service by eating harmful weeds. Thus many harmful plants are kept in check. We have noted that they spin silk, thus forming clothing, that in some cases they are preyed upon, and support an enormous multitude of birds, fishes, and other animals with food. Make a balance sheet showing the benefits and harm done man by insects.

How the Damage done by Insects is Controlled. — The combating of insects by the farmer is controlled and directed by two bodies of men, both of which have the same end in view. These are the Bureau of Entomology of the United States Department of Agriculture and the various state experiment stations.

The Bureau of Entomology works in harmony with the other divisions of the Department of Agriculture, giving the time of its experts to the problems of controlling insects which, for good or ill, influence man's welfare in this country. Such problems as the destruction of the malarial mosquito and control of the typhoid fly; the destruction of harmful insects by the introduction of their natural enemies, plant or animal; the perfecting of the honeybee (see Hodge, *Nature Study and Life*, page 240), and the introduction of new species of insects to pollinate flowers not native to this country (see *Blastophaga*, page 45), are some to which these men are now devoting their time.

All the states and territories (except Indian Territory) have, since 1888, established state experiment stations, which work in coöperation with the government in the war upon injurious insects. These stations are often connected with colleges, so that young

men who are interested in this kind of natural science may have opportunity to learn and to help.

The good done by these means directly and indirectly is very great. Bulletins are published by the various state stations and by the Department of Agriculture, most of which may be obtained free. The most interesting of these from the high school standpoint are the Farmers' Bulletins, issued by the Department of Agriculture, and the Nature Study pamphlets issued by the Cornell University in New York state.

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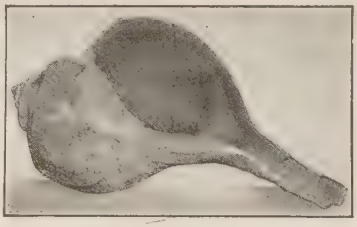
XXI. THE MOLLUSKS

Problem XXXIII (Optional). *A study of mollusks and their enemies with reference to their economic importance. (Laboratory Manual, Prob. XXXIII.)*

To the average high school pupil a clam or oyster on the "half shell" is a familiar object. The soft "body" of the animal lying between the two protecting "valves" of the shell gives the name to this group (Latin *mollis* — soft). Most mollusks have a limy shell, either bivalve (two-valved), as the oyster, clam, mussel, and scallop, or univalve, as in the snail. Usually the univalve shell is spiral in form, some of nature's most beautiful objects being the spiral shells of some marine forms. Still other mollusks, for example, the garden slug, have no external shell whatever.

This limy shell envelope when present, is formed from the outer edge and surface of a delicate body covering called the *mantle*. The mantle may be found in the opened oyster or clam sticking close to the inside of the valve of the shell in which the body rests. Between the mantle and the body of the clam or oyster is a space, the *mantle cavity*. In the space hang the *gills*, platelike striated structures. By means of cilia on the inner surface of the mantle and on the gills a constant current of water is maintained through the mantle cavity bearing oxygen to the gills and carbon dioxide away. This current of water passes, in most mollusks, into and out from the mantle cavity through the *siphons*, the muscular tubes forming the "neck" of the "soft clam" being an example of such an organ.



Fulgar, a univalve mollusk common in Long Island Sound, which does much harm by boring into the shells of edible mollusks.

The food of clams or oysters consists of tiny organisms, plant and animal, which are carried in the current of water to the mouth of the animal, this water current being maintained in part by the action of cilia on the palps or liplike flaps (p. 269) surrounding the mouth. A single muscular foot aids in locomotion when the animal moves about. Many mollusks, as the oyster, are fixed when adult.

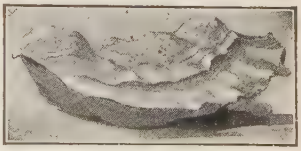
The shallow water of bays and other quiet bodies of salt water where clams and oysters live, literally swarm with tiny plants. The conditions for the growth of such plants is ideal. Water from the rivers containing organic waste and depositing daily its load of mud on the bottom

gives one basis for the support of these plants. The carbon dioxide from the thousands of species of fish, mollusks, crustaceans, worms, and other forms of animal life gives another source of raw food material for the plant. The sunlight penetrating through the shallow waters supplies the energy for making the food. Thus conditions are ideal for rapid multiplication; hence the water becomes alive with all kinds of plant life, especially the lower forms. Among these plants are always found bacteria, both harmless and harmful. Mollusks feed upon these plants, including the bacteria; man feeds on the mollusks, and, if he eats them raw, may eat living bacteria as well. Thus disease might result, and, as a matter of fact, epidemics of typhoid fever have been traced to such a source.

Some Common Mollusks. — The fresh-water clam, a common resident in shallow water in inland ponds and rivers, although not useful for food to man, has become the source of a very important industry. The making of pearl buttons has so depleted the number of adult clams in our Middle West that the state and United States governments have undertaken the study of the life habits of these animals with a view to restocking the rivers. The development of the fresh-water clam or mussel is complicated. The egg develops into a free-swimming larval form which fastens to the gills of a fish and there lives as a parasite until almost mature. Then it drops off and begins life in the sand of the river or lake where it lives.

Shell of fresh-water clam, the left half polished to show the prismatic layer from which buttons are made.

The Oyster. — The chief difference between the oyster and the clam lies in the fact that the oyster is fastened by one valve to some solid object, while the clam or fresh-water mussel moves about. This results in an asymmetry in the shell of the oyster.



Shell of oyster, showing asymmetry.

Oysters are never found in muddy localities, for in such places they would be quickly smothered by the sediment in the water. They are found in nature clinging to stones or on shells or other objects which project a little above the bottom. Here food is abundant and oxygen is obtained from the water surrounding them. Hence oyster raisers throw oyster shells into the water and the young oysters attach themselves.

In some parts of Europe and this country where oysters are raised ar-

tificially, stakes or brush are sunk in shallow water so that the young oyster, which is at first free-swimming, may escape the danger of smothering on the bottom. After the oysters are a year or two old, they are taken up and put down in deeper water as seed oysters. At the age of three and four years they are ready for the market.

The oyster industry is one of the most profitable of our fisheries. Nearly $15,000,000 a year has been derived during the last decade from such sources. Hundreds of boats and thousands of men are engaged in dredging for oysters. Three of the most important of our oyster grounds are Long Island Sound, Narragansett Bay, and Chesapeake Bay.

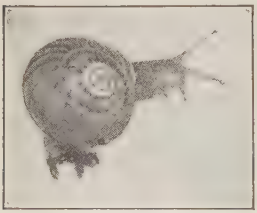
Sometimes oysters are artificially "fattened" by placing them on beds near the mouths of fresh-water streams. Too often these streams are the bearers of much sewage, and the oyster, which lives on microscopic organisms, takes in a number of bacteria with other food. Thus a person might become infected with the typhoid bacillus by eating raw oysters. It is evident that state and city supervision ought to be exercised with reference not only to the sale of shellfish which comes from contaminated localities, but also to prevent the growth of oysters or other mollusks in the neighborhood of the openings of sewers or sewage-bearing rivers.

Clams. — Other bivalve mollusks used for food are clams and scallops. Two species of the former are known to New Yorkers, one as the "round," another as the "long" or "soft-shelled" clams. The former (*Venus mercenaria*) was called by the Indians "quahog," and is still so called in the Eastern states. The blue area of its shell was used by the Indians as wampum, or money. The quahog is now extensively used as food. The "long" clam (*Mya arenaria*) is considered better eating by the inhabitants of Massachusetts and Rhode Island. This clam was highly prized as food by the Indians. The clam industries of the eastern coast aggregate nearly $1,000,000 a year.

Round clam (*Venus mercenaria*): *AAM*, anterior adductor muscle; *ARM*, anterior retractor muscle; *PAM*, posterior adductor muscle; *PRM*, posterior retractor muscle; *F*, foot; *C*, cloacal chamber; *IS*, incurrent siphon; *FS*., excurrent siphon; *EO*, heart; *G*, gills; *M*, mantle; *DGL*, digestive glands; *S*, stomach; *I*, intestine; *P*, palp; *R*, posterior end of digestive tract.

Scallop. — The scallop, another molluscan delicacy, forms an important fishery. Only the single adductor muscle is eaten, whereas in the clam the soft parts of the body are used as food.

Pearls and Pearl Formation. — Pearls are prized the world over. It is a well-known fact that even in this country pearls of some value are sometimes found within the shells of such common bivalves as the fresh-water mussel and the oyster. Most of the finest, however, come from the waters around Ceylon. If a pearl is cut open and examined carefully, it is found to be a deposit of the mother-of-pearl layer of the shell around some central structure. It has been believed that any foreign substance, as a grain of sand, might irritate the mantle at a given point, thus stimulating it to secrete around the substance. It now seems likely that most perfect pearls are due to the growth within the mantle of the clam or oyster of certain parasites, stages in the development of a flukeworm. The irritation thus set up in the tissue causes mother-of-pearl to be deposited around the source of irritation, with the subsequent formation of a pearl.



Forest snail, showing the two tentacles with an eye on the end of each. From photograph by Davison.

Gastropods. — Snails, whelks, slugs, and the like are called *gastropods*, because the foot occupies so much space that most of the organs of the body, including the stomach, are covered by it. Such animals are partially covered by a more or less spirally formed shell which has but one valve. In most gastropods the body is spirally twisted in the shell. In the garden slug, the mantle does not secrete an external shell, and the naked body is symmetrical.

Gastropods of various species do considerable damage, some in the garden, where they feed upon young plants, others in the sea, where they bore into the shells of other living mollusks in order to get out the soft part of the body which they use as food.

The squid. One fourth natural size.

Cephalopods. — Another class of mollusks are those known as *cephalopods*. The name "cephalopod" means head-footed. As the Figure shows, the mouth is surrounded with a circle of tentacles. The shell is internal or lacking, the so-called pen of the cuttlefish being all that remains of the shell in that form. A cuttlefish is strangely modified for the life it leads. It moves rapidly through the water by squirting water from the siphon. It can seize its prey with the suckers on the long tentacles

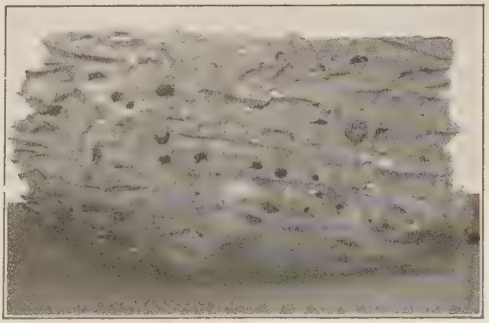
and tear it in pieces by means of its horny, parrotlike beak. It is protected from its enemies and is enabled to catch its prey because of its ability to change color quickly. In this way the animal simulates its surroundings. The cuttlefish has an ink bag near the siphon which contains the black sepia. A few drops of this ink squirted into the water may effectually hide the animal from its enemy.

To this group of animals belongs also the octopus, or devilfish, a cephalopod known to have tentacles over thirty feet in length, the paper nautilus and the pearly nautilus, the latter made famous by our poet Holmes.

Habitat of the Mollusks. — Mollusks are found in almost all parts of the earth and sea. They are more abundant in temperate localities than elsewhere, but are found in tropical and arctic countries. They are found in all depths of water, but by far the greatest number of species live in shallow water near the shore. The cephalopods live near the surface of the ocean, where they prey upon small fish. The food supply evidently determines to a large extent where the animal shall live. Some mollusks are scavengers; others feed on living plants.

We have found in the forms of mollusks studied that almost all mollusks live in the water. There is one great group which forms a general exception to this, certain of the snails and slugs called *pulmonates*. But even these animals are found in damp localities, and at the approach of drought they become inactive, remaining within the shell. The European snail (*Helix pomatia*) imported to this country as a table delicacy exists for months by plugging up the aperture to the shell with a mass of slimy material which later hardens, thus protecting the soft body within.

Economic Importance. — In general the mollusks are of much economic importance. The bivalves especially form an important source of our food supply. Many of the mollusks also make up an important part of the food supply of bottom-feeding fishes. On the other hand, some mollusks, as *natica*, bore into other mollusk shells and eat the animal thus attached. Some boring mollusks, for example the shipworm (*Teredo navalis*), do much damage, especially to wharves, as they make their home in piles. Still others bore holes in soft rock and live there.

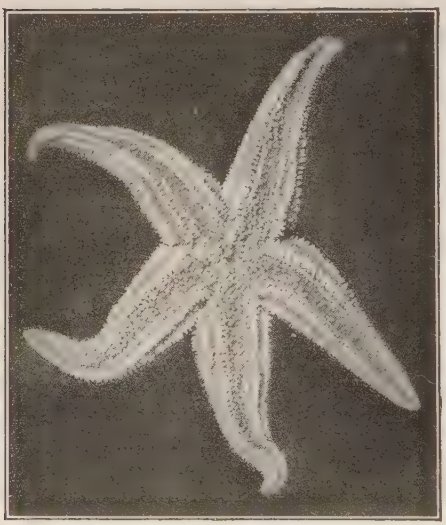


Piece of timber, showing holes bored by the shipworm.

The shells of mollusks are used to a large extent in manufactures and

in the arts, while they form a money basis still in parts of the world. Sepia comes from the cuttlefish.

The Starfish. — By all means the most important enemy of the oyster and other salt-water mollusks is the starfish. The common starfish, as the name indicates, is shaped like a five-pointed star. A limy skeleton which is made up of thousands of tiny plates gives shape to the body and arms. Slow movement is effected by means of tiny suckers, called *tube feet*. Breathing takes place through the skin. The mouth is on the under surface of the animal, and, when feeding, the stomach is protruded and wrapped around its prey. The body of the starfish, as well as that of the sea urchin and others of this group, is spiny; hence the name *Echinoderm* (spiny-skinned) is given to the group.



Ventral or under surface of the starfish. The dark circle in the middle is the mouth, from which radiate the five ambulacral grooves, each filled with four rows of tube feet. Photograph half natural size, by Davison.

Food of the Starfish. — Starfish are enormously destructive of young clams and oysters, as the following evidence, collected by Professor A. D. Mead of Brown University, shows. A single starfish was confined in an aquarium with fifty-six young clams. The largest clam was about the length of one arm of the starfish, the smallest about ten millimeters in length. In six days every clam in the aquarium was devoured. The method of capturing and killing their prey shows that they wrap themselves around the valves of the mollusk and actually pull apart the valves by means of their tube feet, some of which are attached to one valve and some to the other of their victim. Once the soft part of the mollusk is exposed, the stomach envelops it, and it is rapidly digested and changed to a fluid. This it can do because of the five large digestive glands which occupy a large part of each ray, and which pour their digestive fluids into five pouchlike extensions of the stomach extending into each ray.

Hundreds of thousands of dollars' damage is done annually to the oysters in Connecticut alone by the ravages of starfish. During the

summer months the oyster boats are to be found at work raking the beds for starfish, which are collected and thrown ashore by the thousands.

Classification of Mollusks

Class I. *Pelecypoda* (Lamellibranchiata). Soft-bodied unsegmented animals showing bilateral symmetry. Bivalve shell, platelike gills. Examples: clam (*Mya arenaria*), scallop (*pecten*), oyster (*Ostrea*), and fresh-water mussel (*Unio*).

Class II. *Gastropoda*. Soft bodies asymmetrical; univalve shell or shell absent. Some forms breathe by gills, others by lunglike sacs. Examples: pond snail, land snail (*Helix*), and slug.

Class III. *Cephalopoda*. Bilaterally symmetrical mollusks with mouth surrounded by tentacles. Shell may be external (nautilus), internal (squid), or altogether lacking (octopus). Examples: squid, octopus.

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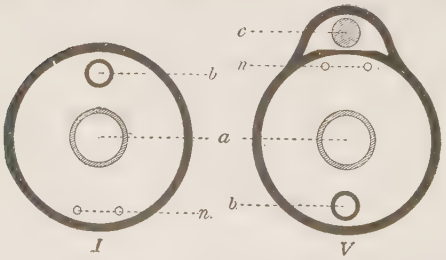
XXII. THE VERTEBRATE ANIMALS

Increasing Complexity of Structure and of Habits in Plants and Animals. — In our study of biology so far we have attempted to get some notion of the various factors which act upon and interact with living things. We have learned something about the various physiological processes of plants and animals, and have found them to be in many respects identical. We have examined a number of forms of plants and have found all grades of complexity, from the one-celled plant, bacterium or pleurococcus, to the complicated flowering plants of considerable size and with many organs. So in animal life the forms we may have studied, from the Protozoa upward, there is constant change, and the change is toward greater complexity of structure and functions. A worm is simpler in structure than an insect, and in many ways, especially by its actions, shows that it is not so high in the scale of life as its more lively neighbor.

We are already awake to the fact that we, as living creatures, are better equipped in the battle for life than our more lowly neighbors, for we are *thinking* creatures, and can change our surroundings at will, while the lower forms of animals are largely controlled by stimuli which come from without; temperature, moisture, light, the presence or absence of food, — all these result in movement and other reactions.



Cross section through (*I*) an invertebrate animal and (*V*) a vertebrate animal: *a*, food tube; *b*, heart; *c*, vertebrate column; *n*, central nervous system.

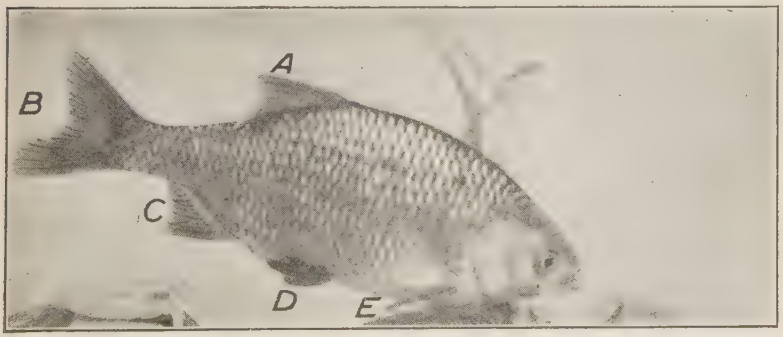
In structure we also differ. Particularly is this difference seen in the skeleton. We call ourselves *vertebrates*, because we have a

bony vertebral column, made up of pieces of bone joined one to another, forming a flexible yet strong support for the muscles and protecting the delicate central nervous system. This kind of an *endoskeleton*, or inside skeleton, is possessed by fishes, frogs, turtles or snakes, and birds, and by mammals, such as the dog, cat, and man. All such animals are called vertebrates. We are now to take up the study of some types of various kinds of vertebrates, with the view to a better understanding of man.

Fishes

Problem XXXIV. *A study of how a fish is fitted for the life it leads.* (*Laboratory Manual, Prob. XXXIV.*)

The Body. — One of our common fresh-water fish is the bream, or golden shiner. The body of the bream runs insensibly into the head, the neck being absent. The long, narrow body with its smooth surface fits the fish admirably for its life in the water. Certain cells in the skin secrete mucus or slime, another adaptation. The position of the scales, overlapping in a backward direction, is yet another adaptation which aids in passing through



The fins of a fish: *A*, dorsal; *B*, caudal; *C*, anal; *D*, pelvic; *E*, pectoral.

the water. Its color, olive above and bright silver and gold below, is also protective. Can you see how?

The Appendages and their Uses. — The appendages of the fish consist of paired and unpaired fins. The paired fins are four in number, and are believed to correspond in position and structure

with the paired limbs of a man. Note the Figure on page **278** and locate the paired *pectoral* and *pelvic* fins. (These are so called because they are attached to the bones forming the pectoral and pelvic girdles. See page **279**.) Find, by comparison with the Figure, the *dorsal*, *anal*, and *caudal* fins. How many unpaired fins are there?

The flattened, muscular body of the fish, tapering toward the caudal fin, is moved from side to side with an undulating motion which results in the movement forward of the fish. This movement is almost identical with that of an oar in sculling a boat. Turning movements are brought about by use of the lateral fins in much the same way as a boat is turned. We notice the dorsal and other single fins are evidently useful as balancing and steering organs.

The Senses. — The position of the eyes at the side of the head is an evident advantage to the fish. Why? The eye is globular in shape. Such an eye has been found to be very nearsighted. Thus it is unlikely that a fish is able to perceive objects at any great distance from it. The eyes are unprotected by eyelids, but the tough outer covering and their position afford some protection.

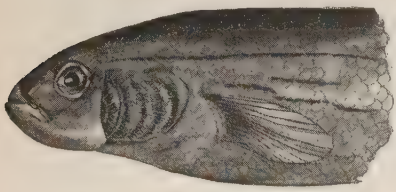
Feeding experiments with fishes show that a fish becomes aware of the presence of food by smelling it as well as by seeing it. The nostrils of a fish can be proved to end in little pits, one under each nostril hole. Thus they differ from our own, which are connected with the mouth cavity. In the catfish, for example, the *barbels*, or horns, receive sensations of smell and taste. The sense of perceiving odor is not as we understand the sense of smell, for a fish perceives only substances that are dissolved in the water in which it lives. The senses of taste and touch appear to be less developed than the other senses.

Along each side of most fishes is a line of tiny pits, provided with sense organs and connected with the central nervous system of the fish. This area, called the *lateral line*, is believed to be sensitive to mechanical stimuli of certain sorts. The "ear" of the fish is under the skin and serves partly as a balancing organ.

A fish must go after its food and seize it, but has no structures for grasping except the teeth. Consequently we find the teeth small, sharp, and numerous, well adapted for holding living prey. The tongue in most fishes is wanting or very slightly developed.

Breathing. — A fish, when swimming quietly or when at rest, seems to be biting when no food is present. A reason for this act is to be seen when we introduce a little finely powdered carmine into the water near the head of the fish. It will be found that a current of water enters the mouth at each of these biting movements and passes out through two slits found on each side of the head of the fish. Investigation shows us that under the broad, flat plate, or *operculum*, forming each side of the head, lie several long, feathery, red structures, the *gills*.

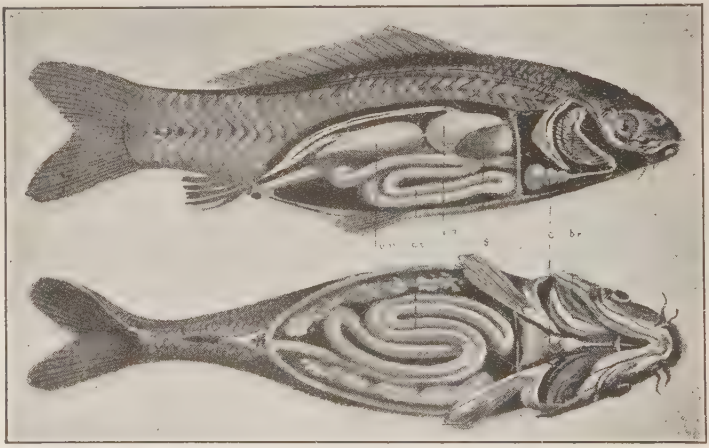
Gills. — If we examine the gills of any large fish, we find that a single gill is held in place by a bony arch, made of several pieces of bone which are hinged in such a way as to give great flexibility to the gill arch, as the support is called. Covering the bony framework, and extending from it, are numerous delicate filaments of flesh, covered with a very delicate membrane or skin. Into each of these filaments pass two blood vessels; in one blood flows downward and in the other upward. Blood reaches the gills and is carried away from these organs by means of two large vessels which pass along the bony arch previously mentioned. In the gill filament the blood comes into contact with the free oxygen of the water bathing the gills. An exchange of gases through the walls of the gill filaments results in the loss of carbon dioxide and a gain of oxygen by the blood.



The head of a fish, with the operculum cut away to show the gills.

Gill Rakers. — If we open wide the mouth of any large fish and look inward, we find that the mouth cavity leads to a funnel-like opening, the gullet. On each side of the gullet we can see the gill arches, guarded on the inner side by a series of sharp-pointed structures, the *gill rakers*. In some fishes in which the teeth are not well developed, there seems to be a greater development of the gill rakers, which in this case are used to strain out small organisms from the water which passes over the gills. Many fishes make such use of the gill rakers. Such are the shad and menhaden, which feed almost entirely on *plankton*, a name given to the small plants and animals found by millions in the water.

Digestive System. — The gullet leads directly into a baglike stomach. There are no salivary glands in the fishes. There is, however, a large liver, which appears to be used as a digestive gland. This organ, because of the oil it contains, is in some fishes, as the cod, of considerable economic importance. Many fishes have outgrowths like a series of pockets from the intestine. These structures, called the *pyloric cæca*, are believed to secrete a digestive fluid. The intestine ends at the vent, which is usually located on the ventral side of the fish, immediately in front of the anal fin.



Anatomy of the carp: *br*, branchiæ, or gills; *c*, heart; *f*, liver; *vn*, swimming bladder; *ci*, intestine.

Swim Bladder. — An organ of unusual significance, called the *swim bladder*, occupies the region just dorsal to the food tube. In young fishes of many species this is connected by a tube with the anterior end of the digestive tract. In some forms this tube persists throughout life, but in other fish it becomes closed, a thin, fibrous cord taking its place. The swim bladder aids in giving the fish nearly the same weight as the water it displaces, thus buoying it up. The walls of the organ are richly supplied with blood vessels, and it thus undoubtedly serves as an organ for supplying oxygen to the blood when all other sources fail. In some fish (the *dipnoi*, p. 284) it has come to be used as a lung.

Circulation of the Blood. — In the vertebrate animals the blood is said to circulate in the body, because it passes through a more or less closed system of tubes in its course around the body. In the fishes the heart is a two-chambered muscular organ, a thin-walled *auricle*, the receiving chamber, leading into a thick-walled muscular *ventricle* from which the blood is forced out. The blood is pumped from the heart to the gills; there it loses some of its carbon dioxide; it then passes on to other parts

of the body, eventually breaking up into very tiny tubes called *capillaries*. From the capillaries the blood returns, in tubes of gradually increasing diameter, toward the heart again. During its course some of the blood passes through the kidneys and is there relieved of part of its nitrogenous waste. (See Chapter XXVII.)

Circulation of blood in the body of the fish is rather slow. The temperature of the blood being nearly that of the surrounding media in which the fish lives, the animal has incorrectly been given the term "cold-blooded."

Plan of circulation in fishes: *a*, auricle; *b*, ventricle; *c*, branchial artery; *e*, branchial veins, bringing blood from the gills, *d*, and uniting in the aorta, *f*; *g*, vena cava, returning blood to heart.

Nervous System. — As in all other vertebrate animals, the brain and spinal cord of the fish are partially inclosed in a series of bony structures called *vertebræ*. The central nervous system consists of a *brain*, with nerves leading to the organs of sight, taste, smell, the ear, and to such parts of the body as possess the sense of touch; a *spinal cord*; and *spinal nerves*. Nerve cells located near the outside of the body send in messages to the central system, which are there received as sensations. Cells of the central nervous system, in turn, send out messages which result in the movement of muscles.

Skeleton. — In the vertebrates, of which the bony fish is an example, the skeleton is under the skin, and is hence called an *endoskeleton*. It consists of a bony framework, the vertebral column, and certain attached bones, the ribs, with other spiny bones to which the unpaired fins are attached. The paired fins are attached to the spinal column by two collections of bones, known respectively as the *pectoral* and *pelvic girdles*. The bones serve in the fish for the attachment of powerful muscles, by means of which locomotion is accomplished. In most fishes, the *exoskeleton*, too, is well developed, modifications appearing from scales to complete armor.

Problem XXXV (Optional). *A study of some of the relations of fishes to their food supply.* (*Laboratory Manual, Prob. XXXV.*)

Food of Fishes. — We have already seen that in a balanced aquarium the balance of food was preserved by the plants, which furnished food for the tiny animals or were eaten by larger ones, — for example, snails or fish. The smaller animals in turn became

food of larger ones. The nitrogen balance was maintained through the excretions of the animals and their death and decay.

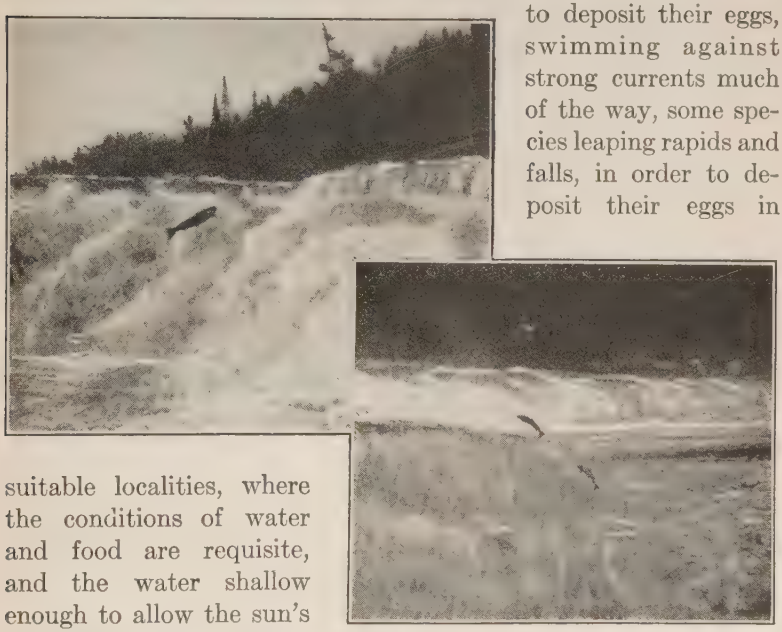
The marine world is a great balanced aquarium. The upper layer of water is crowded with all kinds of little organisms, both plant and animal. Some of these are microscopic in size; others, as the tiny crustaceans, are visible to the eye. On these little organisms some fish feed entirely, others in part. Such are the menhaden [1] (bony, bunker, mossbunker of our coast), the shad, and others. Other fishes are bottom feeders, as the blackfish and the sea bass, living almost entirely upon mollusks and crustaceans. Still others are hunters, feeding upon smaller species of fish or even upon their weaker brothers. Such are the bluefish, squeteague or weakfish, and others.

What is true of salt-water fish is equally true of those inhabiting our fresh-water streams and lakes. It is one of the greatest problems of our Bureau of Fisheries to discover this relation of various fishes to their food supplies so as to aid in the conservation and balance of life in our lakes, rivers, and seas.

The Egg-laying Habits of the Bony Fishes. — The eggs of most bony fishes are laid in great numbers at the time of spawning. This number varies from a few thousand in the trout to many hundreds of thousands in the shad and several millions in the cod. The time of egg-laying is usually spring or early summer. At the time of spawning the male usually deposits milt, consisting of millions of sperm cells, in the water just over the eggs, thus accomplishing fertilization. Some fishes, as sticklebacks, sunfish, toadfish, etc., make nests, but usually the eggs are left to develop by themselves, sometimes attached to some submerged object, but more frequently free in the water. In some eggs a tiny oil drop buoys up the egg to the surface, where the heat of the sun aids development. They are exposed to many dangers, and both eggs and developing fish are eaten, not only by birds, fish of other species, and other water inhabitants, but also by their own relatives and even parents. Consequently a very small percentage of eggs ever reach maturity.

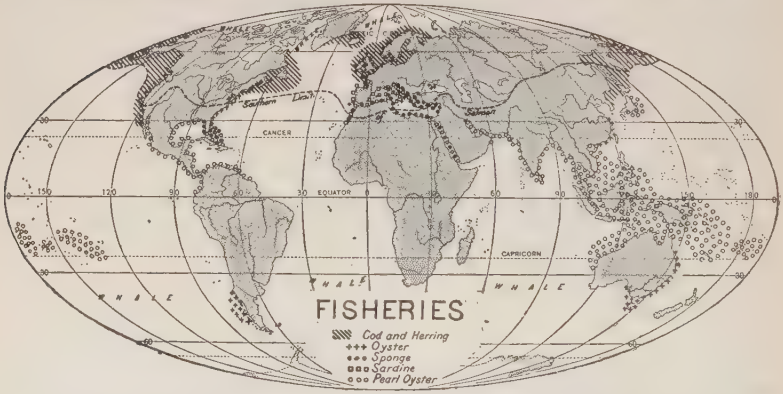
[1] It has been discovered by Professor Mead of Brown University that the increase in starfish along certain parts of the New England coast was in part due to overfishing of menhaden, which at certain times in the year feed almost entirely on the young starfish.

The Relation of the Spawning Habits to Economic Importance of Fish. — The spawning habits of fish are of great importance to us because of the economic value of fish to mankind, not only directly as a food, but indirectly as food for other animals in turn valuable to man. Many of our most desirable food fishes, notably the salmon, shad, sturgeon, and smelt, pass up rivers from the ocean to deposit their eggs, swimming against strong currents much of the way, some species leaping rapids and falls, in order to deposit their eggs in suitable localities, where the conditions of water and food are requisite, and the water shallow enough to allow the sun's rays to warm the water sufficiently to cause the eggs to develop. The Chinook salmon of the Pacific coast, the salmon used in the Western canning industry, travels over a thousand miles up the Columbia and other rivers, where it spawns. The salmon begin to pass up the rivers in early spring, and reach the spawning beds, shallow deposits of gravel in cool mountain streams, before late summer. Here the fish, both males and females, remain until the temperature of the water falls to about 54° Fahrenheit. The eggs and milt are then deposited, and the old fish die, leaving the eggs to be hatched out later by the heat of the sun's rays.



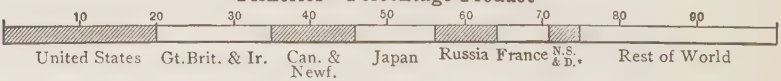
Salmon leaping a fall on their way to their spawning beds. Photographed by Dr. John A. Sampson.

This instinct of this fish and other species to go into shallow rivers to deposit their eggs has been made use of by man. At the time of the spawning migration the salmon are taken in vast numbers. The salmon fisheries net over $16,000,000 annually, the shad at



least $1,500,000, the smelt fishery nearly $150,000 more. The total annual value of the fisheries of the United States is over $50,000,000.

Migration of Fishes. — Some fishes change their habitat at different times during the year, moving in vast schools northward in summer and southward in the winter. In a general way such migrations follow the coast lines. Examples of such migratory fish are the cod, menhaden, herring, and bluefish. The migrations are due to temperature changes, to the seeking after food,



and to the spawning instinct. Some fish migrate to shallower water in the summer and to deeper water in the winter; here the reason for the migration is doubtless the change in temperature.

The herring fisheries have always been a source of wealth to the inhabitants of northern Europe. The banks and shallows of the coast of Newfoundland were undoubtedly known to the Norsemen long before the discovery of this country by Columbus.

Problem XXXVI (Optional). *The artificial propagation of fishes.* (*Laboratory Manual, Prob. XXXVI.*)

The Work of National and State Governments in protecting and propagating Food Fishes. — But the profits from the fisheries are steadily decreasing because of the yearly destruction of untold millions of eggs which might develop into adult fish.

Fortunately, the government through the Bureau of Fisheries, and various states by wise protective laws and by artificial propagation of fishes, are beginning to turn the tide. Certain days of the week the salmon are allowed to pass up the Columbia unmolested. Closed breeding seasons protect our trout, bass, and other game fish, and also prohibit the catching of fish under a certain size. Many fish hatcheries, both government and state, are engaged in artificially fertilizing millions of fish eggs of various species and protecting the young fry until they can be placed in ponds or streams at a size when they can take care of themselves. This artificial fertilization is usually accomplished by first squeezing out the ripe eggs from a female into a pan of water; in a similar manner the milt or sperm cells are obtained, and poured over the eggs. The fertilized eggs are carefully protected, and, after hatching, the young fry are kept in ideal conditions until later they are shipped, sometimes thousands of miles, to their new home.

State and government interposition, however, is in many cases coming too late, for at the present rate of destruction many of our most desirable food fishes will soon be extinct. The sturgeon, the eggs of which are used in the manufacture of the delicacy known as *caviare*, is an example of a fish that is almost extinct in this part of the world. The shad is found in fewer numbers each year, and in fewer rivers as well. The salmon will undoubtedly soon meet the fate of other fishes which are taken at the spawning season, unless conservation of a radical sort takes place.

Classification of Fishes. — The animals we recognize as fishes are grouped by naturalists into four groups: —

1. **The Elasmobranchs.** — These fishes have a skeleton formed of cartilage which has not become hardened with lime. The gills communicate with the surface of the body by separate openings instead of having an operculum. The skin is rough and the eggs few in number.

Sand shark, an elasmobranch. Note the slits leading from the gills. From photograph loaned by the American Museum of Natural History.

Sturgeon (*Acipenser sturio*), a ganoid fish.

In some members of this group the young are born alive. Sharks, rays, and skates are elasmobranchs.

2. **Ganoids.** — The bodies of these are ganoids protected by a series of platelike scales of considerable strength. These fishes are the only remnant of what once was the most powerful group of animals on the earth, the great armored fishes of the Devonian age. The gar pike is an example.

A bony fish.

3. **The Teleosts, or Bony Fishes.** — They compose 95 per cent of all living fishes. In this group the skeleton is bony, the gills are protected by an operculum, and the eggs are numerous. Most of our common food fishes belong to this class.

4. **The Dipnoi, or Lung Fishes.** — This is a very small group, in many respects more like amphibians than fishes, the swim bladder being used as a lung. They live in tropical Africa, South America, and Australia, inhabiting the rivers and lakes there. They withstand drying up in the mud during the dry season, lying dormant for long periods of time in a ball of mud and waking to active life again when the mud coat is removed by immersion in water.

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Amphibia. The Frog

Problem XXXVII. *Some adaptations in a living frog.* (*Laboratory Manual, Prob. XXXVII.*)

Adaptations for Life. — The most common frog in the eastern part of the United States is the leopard frog. It is recognized by its greenish brown body with dark spots, each spot being outlined in a lighter colored background. In spite of the apparent lack of harmony with their surroundings, their color, on the contrary, appears to give almost perfect protection. In some species of frogs the color of the skin changes with the surroundings of the frog, another means of protection.

The leopard frog.

Adaptations for life in the water are numerous. The ovoid body, the head merging into the trunk, the slimy covering (for the frog is provided, like the fish, with mucus cells in the skin), and the powerful legs with webbed feet, are all evidences of the life which the frog leads.

Locomotion. — You will notice that the appendages have the same general position on the body and same number of parts as do your own (upper arm, forearm, and hand; thigh, shank, and foot, the latter much longer relatively than your own). Note that while the hand has four fingers, the foot has five toes, the latter connected by a web. In swimming the frog uses the stroke we all aim to make when we are learning to swim. Most of the energy is liberated from the powerful backward push of the hind legs, which in a resting position are held doubled up close to the body. On land, locomotion may be by hopping or crawling.

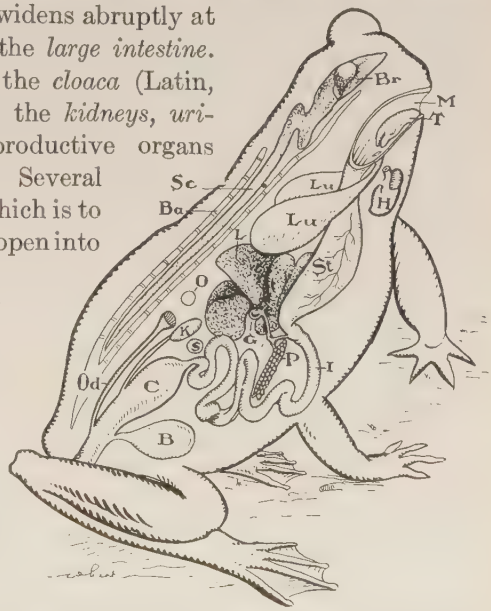
Sense Organs. — The frog is well provided with sense organs. The eyes are large, globular, and placed at the side of the head. When they are closed, a delicate fold, called the *nictitating membrane* (or third eyelid), is drawn over each eye. Frogs probably see best moving objects at a few feet from them. Their vision is much keener than that of the fish. The external ear (*tympanum*) is located just behind the eye on the side of the body. Frogs hear sounds and distinguish various calls of their own kind, as is proved by the fact that frogs recognize the warning notes of their mates when any one is approaching. The inner ear also has to do with balancing the body as it has in fishes and other vertebrates. Taste and smell are probably not strong sensations in a frog or toad. They bite at moving objects of almost any kind when hungry. Experience has taught these animals that moving things, insects, worms, and the like, make good food. These they swallow whole, the tiny teeth being used to hold the food. Touch is a well-developed sense. They also respond to changes in temperature under water, remaining there in a dormant state for the winter when the temperature of the air becomes colder than that of the water.

Breathing. — The frog breathes by raising and lowering the floor of the mouth, pulling in air through the two nostril holes. Then the little flaps over the holes are closed, and the frog swallows this air, thus forcing it down into the baglike lungs. The skin is provided with many tiny blood vessels, and in winter, while the frogs are dormant at the bottom of the ponds, it serves as the only organ of respiration.

Although we shall take up the study of the internal structure of

the frog more in detail when we discuss the structure and uses of the parts of the body in man, we may now learn something of the position and use of some of the structures found within the body cavity.

The Food Tube and its Glands.— The mouth leads like a funnel into a short tube, the *gullet*. On the lower floor of the mouth can be seen the slitlike *glottis* leading to the lungs. The gullet widens almost at once into a long *stomach*, which in turn leads into a much-coiled intestine. This widens abruptly at the lower end to form the *large intestine*. This in turn leads into the *cloaca* (Latin, sewer) into which open the *kidneys*, *urinary bladder*, and reproductive organs (*ovaries* or *spermaries*). Several *glands*, the function of which is to produce digestive fluids, open into the food tube. These digestive fluids, by means of the ferments or enzymes contained in them, change insoluble food materials into a soluble form. This allows of the absorption of food material through the walls of the food tube into the blood. The glands (having the same names and uses as those in man) are the *salivary glands*, which pour their juices into the mouth, the *gastric glands* in the walls of the stomach, and the *liver* and *pancreas*, which open into the intestine. (See Digestion, pages 352–365.)



Internal organs of a frog: M, mouth; T, tongue; Lu, lungs; H, heart; St, stomach; I, small intestine; L, liver; G, gall bladder; P, pancreas; C, cloaca; B, urinary bladder; S, spleen; K, kidney; Od, oviduct; O, ovary; Br, brain; Sc, spinal cord; Ba, back bone.

Circulation. — The frog has a well-developed heart, composed of a thick-walled muscular ventricle and two thin-walled auricles. The heart pumps the blood through a system of closed tubes to all parts of the body. Blood enters the right auricle from all parts of the body; it then con-

tains considerable carbon dioxide; the blood entering the left auricle comes from the lungs, hence it contains a considerable amount of oxygen. Blood leaves the heart through the ventricle, which thus pumps blood containing much and little oxygen. Before the blood from the tissues and lungs has time to mix, however, it leaves the ventricle and by a delicate adjustment in the vessels leaving the heart most of the blood containing much oxygen is passed to all the various organs of the body, while the blood deficient in oxygen, but containing a large amount of carbon dioxide, is pumped to the lungs, where an exchange of oxygen and carbon dioxide takes place by osmosis.

In the tissues of the body wherever work is done the process of burning or oxidation must take place, for by such means only is the energy necessary to do the work released. Food in the blood is taken to the muscle cells or other cells of the body and there oxidized. The products of the burning — carbon dioxide — and any other organic wastes given off from the tissues must be eliminated from the body. As we know, the carbon dioxide passes off through the lungs and to some extent through the skin of the frog, while the nitrogenous wastes, poisons which must be taken from the blood, are eliminated from it in the kidneys. Thus wastes are passed off from the body.

Problem XXXVIII. *The development of a frog.* (*Laboratory Manual, Prob. XXXVI.*)

(*a*) *Conditions favorable.*

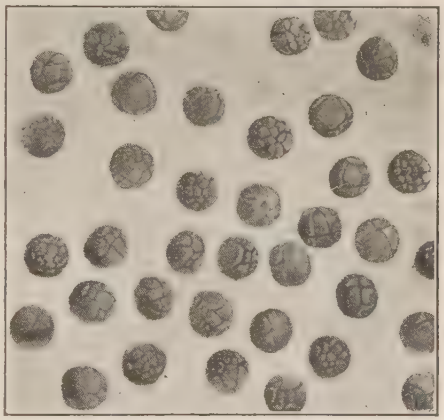
(*b*) *Metamorphosis.*

(*c*) *Development of a toad* (*optional*).

Field and Home Work. — During the first warm days in March or April, look for gelatinous masses of frogs' eggs attached to sticks or water weed in shallow ponds. Collect some and try to hatch them out in a shallow dish in the window at home. Make experiments to learn whether temperature affects the development of the egg in any way. Place eggs in dishes of water in a warm room and in a cold room, also some in the ice box. Make observations for several weeks as to rate of development of each lot of eggs. Also try placing a large number of eggs in one dish, thus cutting down the supply of available oxygen, and in another dish near by, under the same conditions of light and heat, place a few eggs. Do both batches of eggs develop with the same rapidity? In all these experiments be sure to use eggs from the same egg mass, so as to make sure that all are of the same age.

Development. — The eggs of the leopard frog are laid in shallow water in the early spring. Masses of several hundred, which may be found attached to twigs or other supports under water, are de-

posited at a single laying. Immediately before leaving the body of the female they receive a coating of jellylike material, which swells up after the eggs are laid. Thus they are protected from the attack of fish or other animals which might use them as food. The upper side of the egg is dark, the light-colored side being weighted down with a supply of yolk (food). The fertilized egg soon segments (divides into many cells), and in a few days, if the weather is warm, these cells have each grown into an oblong body which shows the form of a tadpole. Shortly after the tadpole wriggles out of the jellylike case and begins life outside the egg. At first it remains attached to some water weed by means of a pair of suckerlike projections; later a mouth is formed at this point, and the tadpole begins to feed upon algæ or other tiny water plants. At this time, about two weeks after the eggs were laid, gills are present on the outside of the body. Soon after, the external gills are replaced by gills which grow out under a fold of the skin which forms an operculum somewhat as in the fish. Water reaches the gills through the mouth and passes out through a hole on the left side of the body. As the tadpole grows larger, legs appear, the hind legs first, although for a time locomotion is performed by means of the tail. In the leopard frog the change from the egg to adult is completed in one summer. In late July or early August, the tadpole begins to eat less, the tail becomes smaller (being absorbed into other parts of the body), and before long the transformation from the tadpole to the young frog is complete. In the green frog and bullfrog the metamorphosis is not completed until the beginning of the second summer. The large tadpoles of such forms



Frogs' eggs from three to ten hours old. All stages from four cells to thirty-two cells may be noted. Photograph, enlarged four times, by Davison.

bury themselves in the soft mud of the pond bottom during the winter.

Shortly after the legs appear, the gills begin to be absorbed, and lungs take their place. At this time the young animal may be seen coming to the surface of the water for air. Changes in the diet of the animal also occur; the long, coiled intestine is transformed into a much shorter one. The animal, now insectivorous in its diet, becomes provided with tiny teeth and a mobile tongue, instead of keeping the horny jaws used in scraping off algæ. After the tail has been completely absorbed and the legs have become full grown, there is no further structural change, and the metamorphosis is complete.

Stages in the life of tadpoles of the green frog. The two large tadpoles are in their second summer. Photographed by Overton.

The Common Toad. — One of the nearest of the allies of the frog is the common toad. The eggs, like those of the frog, are deposited in fresh-water ponds, especially small pools. The egg-laying season is later than that of the frog. The eggs are laid in strings, as many as eleven thousand eggs having been laid by a single toad.

Suggestions for Field Work. — The egg-laying season in New York state is early May. At this time procure a female that has not laid her eggs and place her in an aquarium. If undisturbed, she may lay her eggs in captivity. Compare the bulk of the eggs after they are laid with the size of the

The common toad.

toad that laid them. This apparent discrepancy is caused by the swelling of the gelatinous substance around them. If possible, count the number of eggs laid by one female.[1]

Toad tadpoles may be distinguished from those of the frog, as they are darker in color, and have a more slender tail and a relatively larger body than those of the frog. The metamorphosis occupies only about two months in the vicinity of New York, but varies greatly with the temperature. During the warm weather the tail is absorbed with wonderful rapidity, and the change from a tadpole with no legs to that of the small toad living on land is often accomplished in a few hours. This has given rise to the story that it has rained toads, because during the night thousands of young toads have changed their habitat from the water to the land.

The toad is of great economic importance to man because of its diet. No less than eighty-three species of insects, mostly injurious, have been proved to enter into the dietary.[2] A toad has been observed to snap up one hundred and twenty-eight flies in half an hour. Thus at a low estimate it could easily destroy one hundred insects during a day and do an immense service to the garden during the summer. It has been estimated by Kirkland that a single toad may, on account of the cutworms which it kills, be worth $19.88 each season it lives if the damage done by each cutworm be estimated at only one cent. Toads also feed upon slugs and other garden pests.

Spotted salamander. From photograph loaned by the American Museum of Natural History.

Other Amphibians. – The tree frogs (called tree toads) are familiar to us in the early spring as the "peepers" of the swamps. They are among the earliest of the frogs to lay their eggs. During adult life they spend most of their time on the trunks of trees, where they receive im-

[1] See Hodge, *Nature Study and Life.*

[2] See Kirkland, *Habits, Food,* and *Economic Importance of the American Toad,* Bul. 46, Hatch Experiment Station, Amherst, Mass.

munity from attack because of their color markings. The feet of the tree toad are modified for climbing by having little disks on the ends of the toes, by means of which it is able to cling to vertical surfaces.

Another common amphibian is the newt, a salamander. This smooth-skinned, four-limbed animal, often incorrectly called a lizard, passes its larval life in the water, where it breathes by means of external gills. Later it loses its gills, becomes provided with lungs, and comes out on land. Its coat, which was greenish in the water, now becomes bright orange in color. In this condition we sometimes find them crawling on wood roads after a rain. After over two years' life on land, it again returns to the water, becomes green with red spots (as seen in the Figure), and now is able to reproduce its kind. Some salamanders never have lungs, but breathe through the moist skin.

Newt. From photograph loaned by the American Museum of Natural History.

Still other amphibians are the mud puppies, sirens or mud eels, and the axolotl. All of the above animals differ from the reptiles in having a smooth skin with no scales, and in passing the early stage of their existence in the water.

Characteristics of Amphibia. — The frog belongs to the class of vertebrates known as Amphibia. As the name indicates (*amphi*, both, and *bia*, life), members of this group pass more or less of their life in the water, although in the adult state they are provided with lungs. In the earlier stages of their development they take oxygen into the blood by means of gills. At all times, but especially during the winter, the skin serves as a breathing organ. The skin is soft and unprotected by bony plates or scales. The heart has three chambers, two auricles and one ventricle. Most amphibians undergo a complete metamorphosis.

Classification of Amphibia Mentioned

Order I. *Urodela.* Amphibia having usually poorly developed appendages. Tail persistent through life. Examples: mud puppy, newt, salamander.

Order II. *Anura.* Tailless Amphibia, which undergo a metamorphosis, breathing by gills in larval state, by lungs in adult state. Examples: toad and frog.

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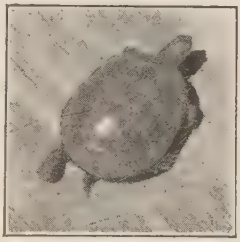
Reptiles

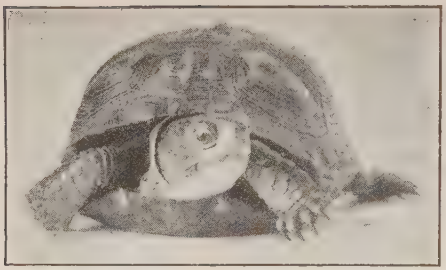
Turtles and Tortoises, Adaptations for Life. — The turtles and tortoises, the latter land animals, form a large and interesting group. The body is flattened, and is covered on the dorsal and ventral sides by a bony framework. This covering is composed of plates cemented to the true bone underneath, the whole forming one horny cover. This covering, an adaptation for protection, is more perfect in the box tortoise, where a hinge on the ventral side allows the animal to retreat within the shell, the head and legs being completely covered.



Western painted turtle.

Adaptations for Food Getting. — The long neck and powerful horny jaws are factors in the food procuring. Turtles have no teeth. Prey is seized and held by the jaws, the claws of the front legs being used to tear the food.

Turtles are very strong for their size. The stout legs carry the animal slowly on land, and in the water, being slightly webbed, they are of service in swimming. In some water turtles the front limbs are modified into flippers for swimming. The strong claws are used for digging, especially at egg-laying season, for some turtles dig holes in sandy beaches in which the eggs are deposited.

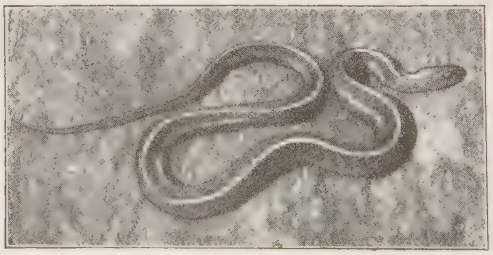


Box tortoise (*Cistudo carolina*). From photograph loaned by the American Museum of Natural History.

Some Different Turtles. — Turtles are mostly aquatic in habit. Some exceptions are the box tortoise (*Cistudo carolina*) and the giant tortoise of the Galapagos Islands. Many of the sea-water turtles are of large size, the leatherback and the green turtle often weighing six hundred to seven hundred pounds each. The flesh of the green turtle and especially the diamond-back terrapin, an animal found in the salt marshes along our southeastern coast, are highly esteemed as food. Unfortunately for the preservation of the species, these animals are usually taken during the breeding season when they go to sandy beaches to lay their eggs.

The Gila monster. Photograph one tenth natural size, by Davison.

Lizards. — Lizards may be recognized by the long body with four legs of nearly equal size. The body is covered with scales. The animal never lives in water, it is active in habit, and it does not undergo a metamorphosis. Lizards are generally harmless creatures, the Gila monster of New Mexico and Arizona, a poisonous variety, being one exception. Lizards are of economic importance to man, because they eat insects and include the injurious ones in their dietary. The iguana of Central America and South America, growing to a length of three feet or more, has the distinction of being one of the few edible lizards.



A garter snake, one of our commonest harmless reptiles.

Snakes. — Probably the most disliked and feared of all animals are the snakes. This feeling, however, is rarely deserved, for, on the whole, our common snakes are beneficial to man. The black snake and the milk snake feed largely on injurious rodents (rats, mice, etc.), the pretty green snake eats injurious insects, and the little DeKays snake feeds partially on slugs. If it were not that the rattlesnake and the copperhead are venomous, they also could be said to be useful, for they live on English sparrows, rats, mice, moles, and rabbits.

Snakes are almost the only legless vertebrates. Although the limbs are absent, still the pelvic and pectoral girdles are developed. The very long backbone is made up of a large number of vertebræ, as many as four hundred being found in the boa constrictor. Ribs are attached to all vertebræ in the region of the body cavity.

Skull of boa constrictor, two thirds natural size. Note the inpointing teeth. Photograph by Davison.

Locomotion. — Locomotion is performed by pulling and pushing the body along the ground, a leverage being obtained by means of the broad, flat scales, or *scutes*, with which the ventral side of the body is covered. Snakes may move without twisting the body. This is accomplished by a regular drawing forward of the scutes and then pushing them backward rather violently.

Feeding Habits. — The bones of the jaw are very loosely joined together. Thus the mouth of the snake is capable of wide distention. It holds its prey by means of incurved teeth, two of which (in the poisonous snakes) are hollow or grooved, and serve as a duct for the passage of poison. The poison glands are at the base of the curved fangs in the upper jaw. The tongue is very long and cleft at the end. It is an organ of touch and taste, and is not, as many people believe, used as a sting. The food is swallowed whole, and pushed down by rythmic contractions of the muscles surrounding the gullet. They usually refuse other than living prey.

Adaptations. — Snakes are usually protectively colored. They are not extremely prolific animals, but hold their own with other forms of life, because of their numerous adaptations for protection, their noiseless movement, protective color, and, in some cases, by their odor and poison.

Poisonous Snakes. — Not all snakes can be said to be harmless. The bite of the rattlesnake of our own country, although dangerous, seldom kills. The dreaded cobra of India has a record of over two hundred and fifty thousand persons killed in the last thirty-five years. The Indian government yearly pays out large sums for the extermination of venomous snakes, over two hundred thousand of which have been killed during a single year.

Alligators and Crocodiles. — The latter are mostly confined to Asia and Africa, while the former are natives of North and South America. The chief structural difference between them is that the teeth in alligators

Young alligator. One fourth natural size.

are set in long sockets, while those of the crocodile are not. Both of these great lizardlike animals have broad, vertically flattened tails adapted to swimming. The eyes and tip of the snout, the latter holding the nostril holes, protrude from the head, so that the animal may float motionless near the surface of the water with only eyes and nostrils visible. The nostrils are closed by a valve when the animal is under water. These reptiles feed on fishes, but often attack large animals, as horses, cows, and even man. They seek their prey chiefly at night, and spend the day basking in the sun. The crocodiles of the Ganges River in India levy a yearly tribute of many hundred lives from the natives.

Characteristics of Reptilia. — The animals described belong to the class of vertebrates known as Reptilia. Such animals are characterized by having scales developed from the skin. These in the turtle have become bony and are connected with the internal skeleton. Reptiles always breathe by means of lungs, differing in this respect from the amphibians. They show their distant

relationship to birds in that their large eggs are incased in a leathery, limy shell.

CLASSIFICATION OF REPTILES

ORDER I. *Chelonia* (turtles and tortoises). Flattened reptiles with body inclosed in bony case. No teeth or sternum (breastbone). Examples: snapping turtle, box tortoise.

ORDER II. *Lacertilia* (lizards). Body covered with scales, usually having two-paired appendages. Breathe by lungs. Examples: fence lizard, horned toad.

ORDER III. *Ophidia* (snakes). Body elongated, covered with scales. No limbs present. Examples: garter snake, rattlesnake.

ORDER IV. *Crocodilia*. Fresh-water reptiles with elongated body and bony scales on skin. Two paired limbs. Examples: alligator, crocodile.

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Birds

Problem XXXIX. *Study of some adaptations in and reactions of birds.* (*Laboratory Manual, Prob. XXXIX.*)

Adaptations. — Birds among all other animals are known by their covering of feathers and the peculiar modification of the fore limbs for flight. In no other group of animals may we study adaptations so well as here.

Field Work. — Bird activities may best be studied out of doors. Any city park offers more or less opportunity for such study, for several of our native birds make the parks their home. If not these, then the English sparrow can be found anywhere in the East. The best time for making observations is early in the morning, especially in the spring season.

Body. — The body of a bird, under its covering of feathers, is rounded and more or less pointed at each end. Powerful muscles,

attached to the wings, aid in locomotion, while the wing itself, a modified arm, is one of the most evident adaptations to life in the air.

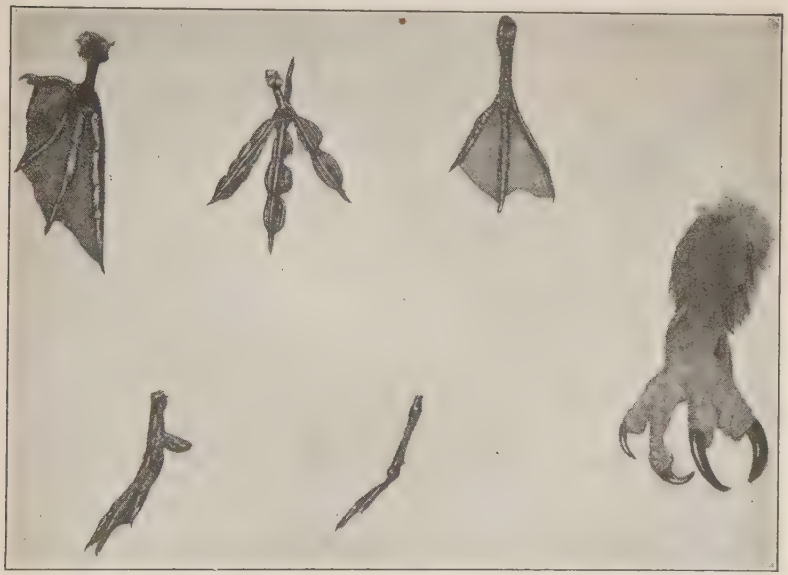
Flight. — Watch a bird in flight. The tip of the wing usually describes a curve which results in the forming of the figure 8. The rate of movement of the wing differs greatly in different birds. The wing of a bird is slightly concave on the lower surface when outstretched. Thus on the downward stroke of the wing more resistance is offered to the air. Birds with long, thin wings, as the hawks and gulls, move the wing in flight with much less rapidity than those with short, wide wings, as the grouse or quail. The latter birds start with much less apparent effort than the birds with longer wings; they are, however, less capable of sustained flight.

Feathers of a meadow lark. Which of the above are used for flight? How do you know? From photograph loaned by the American Museum of Natural History.

Feathers. — Few people realize that the body of a bird is not completely covered with feathers. Featherless areas can be found on the body of any common bird, although tiny "pin feathers" are found on such areas as well as on other parts of the body. Soft down feathers cover the body, serving for bodily warmth. Larger feathers give the rounded contour to the body. In the wings we find quill feathers; these are adapted for service in flight by having a long hollow shaft, from which lateral interlocking branches are given off, the whole making a light structure offering considerable resistance to the air. Feathers are developed from the outer layer of the skin, and are formed in almost exactly the same manner as are the scales of a fish or a lizard. The first feathers developed on the body

are evidently for protection against cold and wet, but later in life they serve other uses. The feathers of most male birds are brightly colored. This seems to make them attractive to the females of the species; thus the male may win its mate.

Adaptations in the Lower Limbs. — The ankle of a bird is extremely long and reptile-like. Scales are found on the ankle and foot. The most extraordinary adaptations are found in the feet of various birds. Some have the foot adapted to perching, others for swim-



Adaptations in the feet of birds. Explain, after reading the paragraph on adaptation in the lower limbs, how each of the above feet is fitted to do its work. From photograph loaned by the American Museum of Natural History.

ming, others wading, etc. We are able, by looking at the feet of a bird, to decide almost certainly its habitat, method of life, and perhaps its food.

In the perching birds we find three toes in front and one behind, the hind toe playing an important part in holding the foot in place. In swallows, rapid and untiring flyers, the feet are small. In the case of the parrots, where the foot is used for holding food, climbing, and clinging, we find the four-clawed toes arranged two in front and

two behind. Hawks and eagles are provided with strong talons with which the prey is seized and killed.

Adaptation for semiaquatic life is seen in plovers, herons, or storks, where long legs and long toes enable the birds to seek their food in soft mud among reeds or lily pads, or along sand flats. True aquatic birds, on the other hand, are provided with webbed toes. The foot of the common barnyard duck, for example, is much like that of the alligator. In the ostrich and cassowary the wings are not used for flight; here the lower limbs have taken up the function of rapid motion.

Perching. — The habit of perching is an interesting one. In many perching birds the tendons of the leg and foot, which regulate the toes, are self-locking; while asleep such birds hold themselves perfectly. A certain part of the ear, known as the *semicircular canals*, has to do with the function of balancing. In the flamingoes and other birds, which do not perch, balancing appears to be automatic; thus the bird is able to sleep when in an upright position.

Skeleton of a fowl: *C*, clavicle; *CV*, cervical vertebræ; *K*, keeled sternum; *PG*, pelvic girdle; *PcG*, bones of pectoral girdle (except clavicle).

Tail. — The tail is sometimes used in balancing; its chief function, however, appears to be that of a rudder during flight. Most birds have under the skin of the tail a large oil gland, whence comes the supply of oil that is used in waterproofing the feathers in preening.

The Skeleton. — The skeleton combines lightness, flexibility, and strength. Many bones are hollow or have large spongy cavities. The bones of the head and neck show many and varied adaptations to the life that the bird leads. The vertebræ which form the framework of the neck are strong and flexible. They vary in shape and

in number. The swan, seeking its food under water, has a neck containing twenty-three long vertebræ; the English sparrow, in a different environment, has only fourteen short ones. Some bones, notably the breastbone, are greatly developed in flying birds for the attachment of the muscles used in flight.

Bill. — The form of the bill shows adaptation to a wonderful degree, the bills varying greatly according to the habits of the birds.

Adaptations in the bills of birds. Could we tell anything about the food of a bird from its bill? Do these birds all get their food in the same manner? Do they all eat the same kind of food?

A duck has a flat bill for pushing through the mud and straining out the food; a bird of prey has a curved or hooked beak for tearing; the woodpecker has a sharp, straight bill for piercing the bark of trees in search of the insect larvæ which are hidden underneath.

Birds do not have teeth. The edge of the bill may be toothlike, as in some fish-eating ducks; these, however, are not true teeth. Frequently the tongue has sharp toothlike edges which serve the same purpose as the recurved teeth of the frog or snake.

Adaptations for Active Life. — The rate of respiration, of heart-beat, and the body temperature are all higher in the bird than in man.

This is one of the greatest adaptations to the active life led by a bird. Man breathes from twelve to fourteen times per minute. Birds breathe from twenty to sixty times a minute. The lungs are not large, the bronchial tubes being continued through the lungs into hollow spaces filled with air, which are found between the organs of the body. Only the lungs, however, are used for breathing. Because of the increased activity of a bird, there comes a necessity for a greater and more rapid supply of oxygen, an increased blood supply to carry the material to be used up in the release of energy, and a means of rapid excretion of the wastes resulting from the process of oxidation. A bird may be compared to a high-pressure steam engine; in order to release the energy which it uses in flight, a large quantity of fuel which will oxidize quickly must be used. Birds are large eaters, and the digestive tract is fitted to digest the food quickly and to release the energy when needed, by having a large crop in which food may be stored in a much softened condition. As soon as the food is part of the blood, it may be sent rapidly to the places where it is needed, by means of the large four-chambered heart and large blood vessels.

The high temperature of the bird is a direct result of this rapid oxidation; furthermore, the feathers and the oily skin form an insulation which does not readily permit of the escape of heat. This insulating cover is of much use to the bird in its flights at high altitudes, where the temperature is often very low.

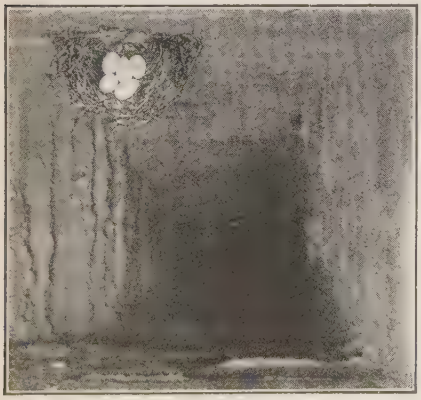
The Nervous System and the Senses. — The central nervous system is well developed. A large forebrain is found, which, according to a series of elaborate experiments with pigeons, is found to have to do with the conscious life of the bird. The cerebellum takes care of the acts which are purely mechanical.

Sight is probably the best developed of the senses of a bird. The keenness of vision of a hawk is proverbial. It has been noticed that in a bird which hunts its prey at night, the eyes look toward the front of the face. In a bird which is hunted, as in the dove, the eyes are placed at the side of the head. In the case of the woodcock, which feeds at night in the marshes, and which is in constant danger from attack by owls, the eyes have come to lie far back on the top of the head. Hearing is also well developed in most birds; this fact may be demonstrated with any canary.

The sense of smell does not appear to be well developed in any bird, and is especially deficient in seed-eating birds.

Nesting Habits. — Among the most interesting of all instincts shown by birds are the habits of nest building. We have found that some invertebrates, as spiders and ants, protect the eggs when laid. In the vertebrate group some fishes (as the sunfish and stickleback) make nests for the deposition of the eggs. But most fishes, and indeed other vertebrates lower than the birds, leave the eggs to be hatched by the heat of the sun. Birds incubate their eggs, that is, hatch them, by the heat of their own bodies. Hence a nest, in which to rest, is needed. The ostrich is an exception; it makes no nest, but the male and the female take turns in sitting on the eggs. Such birds as are immune from the attack of enemies because of their isolation or their protective coloration (as the puffins, gulls, and terns), build a rough nest among the rocks or on the beach. The eggs, especially those of the tern, are marked and colored so as to be almost indistinguishable from the rocks or sand on which they rest. Other birds have made the nest a home and a place of refuge as well as a place to hatch the eggs. Such is the nest of the woodpecker in the hollow tree and the hanging nest of the oriole. Some nests which might be easily seen because of their location are often rendered inconspicuous by the builders; for example, the lichen-covered nest of the humming birds.

Nest of a phœbe under the barn floor.



Nest of the chimney swift.

Care of the Young. — After the eggs have been hatched, the young in most cases are quite dependent upon the parents for food. Most young birds are prodigious eaters; as a result they grow very rapidly. It has been estimated that a young robin eats two or

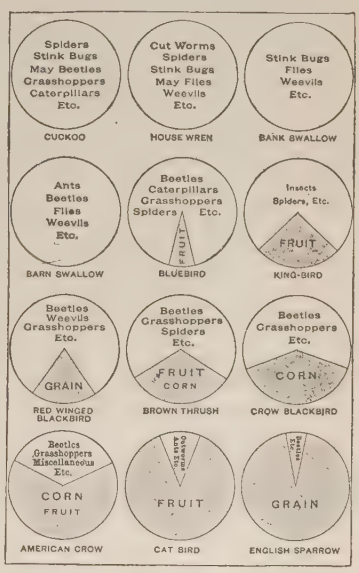
Common tern (*Sterna hirundo*) and young, showing nesting and feeding habits. From group at American Museum of Natural History.

three times its own weight in worms every day. Many other young birds, especially kingbirds, are rapacious insect eaters. In the case of the pigeons and some other birds, food is swallowed by the mother, partially digested in the crop, and then regurgitated into the mouths of the young nestlings.

Problem XL. *How birds are of economic importance.* (*Laboratory Manual, Prob. XL.*)

Food of Birds. — The food of birds makes them of the greatest economic importance to our country. This is because of the relation of insects to agriculture. A large part of the diet of most of our native birds includes insects harmful to vegetation. Investi-

gations undertaken by the United States Department of Agriculture (Division of Biological Survey) show that a surprisingly large number of birds once believed to harm crops really perform a service by killing injurious insects. Even the much maligned crow lives to some extent upon insects. During the entire year, the crow has been shown to eat about 25 per cent insect food and 29 per cent grain. In May, when the grain is sprouting, the crow is a pest, but he makes up for it during the remainder of the summer by eating harmful insects. The robin, whose presence in the cherry tree we resent, during the rest of the summer does untold good by feeding upon noxious insects. Birds use the food substances which are most abundant around them at the time.[1]



Food of some common birds.

Not only do birds aid man in his battles with destructive insects, but seed-eating birds eat the seeds of weeds. Our native sparrows (not the English sparrow), the doves, partridges, and other forms feed largely upon the seeds of many of our common weeds. This fact alone is sufficient to make birds of vast economic importance.

[1] The following quotation from I. P. Trimble, *A Treatise on the Insect Enemies of Fruit and Shade Trees*, bears out this statement: "On the fifth of May, 1864, . . . seven different birds . . . had been feeding freely upon small beetles. . . . There was a great flight of beetles that day; the atmosphere was teeming with them. A few days after, the air was filled with Ephemera flies, and the same species of birds were then feeding upon them."

During the outbreak of Rocky Mountain locusts in Nebraska in 1874-1877, Professor Samuel Aughey saw a long-billed marsh wren carry thirty locusts to her young in an hour. At this rate, for seven hours a day, a brood would consume 210 locusts per day, and the passerine birds of the eastern half of Nebraska, allowing only twenty broods to the square mile, would destroy daily 162,771,000 of the pests. The average locust weighs about fifteen grains, and is capable each day of consuming its own weight of standing forage crops, which at $10 per ton would be worth $1743.26. This case may serve as an illustration of the vast good that is

Not all birds are seed or insect feeders. Some, as the cormorants, ospreys, gulls, and terns, are active fishers. Near large cities gulls especially act as scavengers, destroying much floating garbage that otherwise might be washed ashore to become a menace to health. Sea birds also live upon shellfish and crustaceans (as small crabs, shrimps, etc.); some even eat lower organisms. The kea parrot, once a fruit eater, now takes its meal from the muscles forming the backs of living sheep. Birds of prey (owls) eat living mammals, including many rodents, for example, field mice, rats, and other pests.

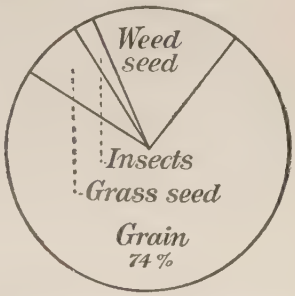
Extermination of our Native Birds. — Within our own times we have witnessed the almost total extermination of some species of our native birds. The American passenger pigeon, once very abundant in the Middle West, is now practically extinct. Audubon, the greatest of all American bird lovers, gives a graphic account of the migration of a flock of these birds. So numerous were they that when the flock rose in the air the sun was darkened, and at night the weight of the roosting birds broke down large branches of the trees in which they rested. To-day hardly a single specimen of this pigeon can be found, because they were slaughtered by the hundreds of thousands during the breeding season. At the present time nearly $3000 is offered to the person finding a pair of *nesting* passenger pigeons. The wholesale killing of the snowy egret to furnish ornaments for ladies' headwear is another example of the improvidence of our fellow-countrymen. Charles Dudley Warner said, "Feathers do not improve the appearance of an ugly woman, and a pretty woman needs no such aid." Wholesale killing for plumage, eggs, and food, and, alas, often for mere sport, has caused the decrease of our birds to 46 per cent in thirty states and territories within the past fifteen years. Every crusade against indiscriminate killing of our native birds

done every year by the destruction of insect pests fed to nestling birds. And it should be remembered that the nesting season is also that when the destruction of injurious insects is most needed; that is, at the period of greatest agricultural activity and before the parasitic insects can be depended on to reduce the pests. The encouragement of birds to nest on the farm and the discouragement of nest robbing are therefore more than mere matters of sentiment; they return an actual cash equivalent, and have a definite bearing on the success or failure of the crops. — *Year Book of the Department of Agriculture.*

should be welcomed by all thinking Americans. Without the birds the farmer would have a hopeless fight against insect pests. The effect of killing native birds is now well seen in Italy and Japan, where insects are increasing and do greater damage each year to crops and trees.

Of the eight hundred or more species of birds in the United States, only two species of hawks (Cooper's and the sharp-shinned hawk), the great horned owl, the cowbird, and the English sparrow may be considered as enemies of man.

The English Sparrow. — The English sparrow is an example of a bird introduced for the purpose of insect destruction, that has done great harm because of its relation to our native birds. Introduced at Brooklyn in 1850 for the purpose of exterminating the cankerworm, it soon abandoned an insect diet and has driven out most of our native insect feeders. Investigations by the United States Department of Agriculture have shown that in the country these birds and their young feed to a large extent upon grain, thus showing them to be injurious to agriculture. Dirty and very prolific, it already has worked its way from the East as far as the Pacific coast. In this area the bluebird, song sparrow, and yellowbird have all been forced to give way, as well as many larger birds of great economic value and beauty. The English sparrow has become a national pest, and should be exterminated in order to save our native birds. It is feared in some quarters that the English starling which has recently been introduced into this country may in time prove a pest as formidable as the English sparrow.



The proportions of food of the English sparrow.

Geographical Distribution and Migrations. — Most of us are aware that some birds remain with us in a given region during the whole year, while other birds appear with the approach of spring, departing southwards with the warm weather in the fall of the year. Such birds we call *migrants*, while those that remain the year round are called *residents*.

In Europe, where the problem of bird migration has been

studied carefully, migrations appear to take place along well-defined paths. These paths usually follow the coast very exactly, although in places they may take the line of coast that existed in former geological times. In this country the Mississippi valley, a former arm of the sea, forms one line of migration, while the north Atlantic seacoast forms another route.[1]

It has been shown that the southern movement of migratory birds in the fall of the year is not due entirely to the advent of cold weather, but is largely a matter of adjustment to food supply. A migrant almost always depends upon fruits, seeds, and grains as part of its food. Most winter residents, as the crow, are omnivorous in diet. Others, as the sparrows, may be seed eaters, but under stress may change their diet to almost anything in the line of food; still others, as the woodpeckers, although insect-eating birds, manage to find the desired food tucked away under the bark of trees. Many insect-eating birds, however, because their food is found on green plants, appear to be forced southward by the cold weather.

African ostrich (*Struthio camelus*).

Classification of Birds. — Birds are divided into two great groups, depending on the development of the *keel;* that is, the part of the breastbone to which the muscles used in flight are attached. Hence all flying birds are placed in a group called the *Carinatæ.*

Birds in which the keel of the breastbone is not well developed, such

[1] There is opportunity for a careful observer to learn much of the spring or fall migrations in the particular part of the country in which he resides. All information thus obtained should be sent to the secretary of the American Ornithologists' Union or to W. W. Cooke of the Biological Survey, who has done much to establish what we already know about bird migration in this country.

as the ostrich and cassowary, are said to belong to the *Ratitæ*. These birds make up for their lack of wing development by having the legs strong and long.

The flying birds are further subdivided into a number of orders, the classification based upon the adaptations of different parts of the bird, especially the legs and feet, the wings and the bill, to different functions. We shall not trouble ourselves to learn all the different groups, but shall content ourselves with picking out some of the more evident and important ones, especially those which we might meet in field trips.

White-throated sparrow (*Zonotrichia albicollis*).

I. **Perching Birds.** — To this order belong most of our common birds, — sparrows, swallows, larks, blackbirds, orioles, kingbirds, and many others well known to every bird lover. In this group the toes are so placed, three toes being turned forward and one backward, as to be perfectly adapted to perching. A large number of our sweetest songsters belong among the perchers, the warblers, wrens, thrushes, bluebirds, and, last but not least, our robin.

A.

B.

A, ptarmigan in winter; *B*, ptarmigan in summer. How do you account for the change in plumage? May this change be of use to the bird?

II. **The Fowls or Gallinaceous Birds.** — This order is of great economic importance. From the jungle fowl, found wild in the jungles of India, most of our domesticated fowls have descended.

Other familiar examples are the turkeys, quails, partridge or ruffed grouse, and the pheasants and prairie chickens. In this group the legs are strong and stout, the body thickset, the bill and claws rather blunt. Birds of this order do not fly far in a state of nature, preferring to live on or near the ground. Such birds as the ruffed grouse, which nest on the ground, are almost invariably protectively colored. Another interesting example of protective resemblance in this group is seen in the ptarmigan. This bird in the winter is white as the snow which surrounds it; in the spring it molts, turning to a gray and white, thus resembling the lichens among which it feeds.

Golden eagle (*Aquila chrysaëtos*). North America and Europe. Copyright, 1901, by N.Y. Zoölogical Society.

III. **Birds of Prey.** — These birds are characterized by the strong hooked beak, adapted to tearing, and by the sharp claws, which are curved and strong. Members of this group that are best known to us are the hawks, the condor, with its great sweep of ten feet from wing to wing, and the eagle.

IV. **Waders.** — These are birds with unusually long legs and long necks, the latter character being a natural correlation of greatest service in food getting. Examples are the mud hen or coot, the snipe, crane, heron, and stork. The last two are the giants of the group.

The Swimmers and Divers. — Birds placed in these orders have the feet webbed; the wings are often adapted for long and swift flight. In this division are placed the gulls, terns, ducks, geese, loons, auks, and puffins.

Other Orders. — Other orders of birds include the doves, the only remaining native representative being the mourning dove; the woodpeckers, strong and long of bill, the friend of the lumberman as a savior of the trees from boring pests which live under the bark; the swifts and humming birds, the latter among the tiniest of all vertebrate animals; and the parrots, of which we have only one native form, the Carolina paroquet (*Conurus carolinensis*). This bird once had a range north as far as the Great Lakes; now it is found only in South America.

Relationship of Birds and Reptiles. — The birds afford an interesting example of how the history of past ages of the earth has given a clew to the structural relation which birds bear to other animals. Several years ago, two fossil skeletons were found in Europe of a birdlike creature which

had not only wings and feathers, but also teeth and a lizardlike tail. From these fossil remains and certain structures (as scales) and habits (as the egg-laying habits), naturalists have concluded that birds and reptiles in distant times were nearly related and that our existing birds probably developed from a reptile-like ancestor millions of years ago.

Classification of Birds

Division I. *Ratitæ*. Running birds with no keeled breastbone. Examples: ostrich, cassowary.

Division II. *Carinatæ*. Birds with keeled breastbone.

Order i. *Passeres*. Perching birds; three toes in front, one behind. One half of all species of birds are included in this order. Examples: sparrow, thrush, swallow.

Order ii. *Gallinæ*. Strong legs; feet adapted to perching. Beak stout. Examples: jungle fowl, grouse, quail, domestic fowl.

Order iii. *Raptores*. Birds of prey. Hooked beak. Strong claws. Examples: eagle, hawk, owl.

Order iv. *Grallatores*. Waders. Long neck, beak, and legs. Examples: snipe, crane, heron.

Order v. *Natatores*. Divers and swimmers. Legs short, toes webbed. Examples: gull, duck, albatross.

Order vi. *Columbæ*. Like Gallinæ, but with weaker legs. Examples: dove, pigeon.

Order vii. *Picariæ*. Woodpeckers. Two toes point forward, two backward, and adaptation for climbing. Long, strong bill.

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elementary

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Mammals

Mammals. — Dogs and cats, sheep and pigs, horses and cows, all of our domestic animals (and man himself), have characters of structure which cause them to be classed as the type of vertebrate

animal known as mammals. They, like some other vertebrates, have lungs and warm blood. They also have a hairy covering and bear young developed to a form similar to their own,[1] and nurse them with milk secreted by glands known as the *mammary glands;* hence the term "mammal."

Instincts. — Mammals are considered the highest of vertebrate animals, not only because of their complicated structure, but because their instincts are so well developed. Monkeys certainly seem to have many of the mental attributes of man.

Professor Thorndike of Columbia University sums up their habits of learning as follows: —

"In their method of learning, although monkeys do not reach the human stage of a rich life of ideas, yet they carry the animal method of learning, by the selection of impulses and association of them with different sense-impressions, to a point beyond that reached by any other of the lower animals. In this, too, they resemble man; for he differs from the lower animals not only in the possession of a new sort of intelligence, but also in the tremendous extension of that sort which he has in common with them. A fish learns slowly a few simple habits. Man learns quickly an infinitude of habits that may be highly complex. Dogs and cats learn more than the fish, while monkeys learn more than they. In the number of things he learns, the complex habits he can form, the variety of lines along which he can learn them, and in their permanence when once formed, the monkey justifies his inclusion with man in a separate mental genus."

Adaptations in Mammalia. — Of the thirty-five hundred species, most inhabit continents; few species are found on different islands, and some, as the whale, inhabit the ocean. They vary in size from the whale and the elephant to tiny shrew mice and moles. Adaptations to different habitat and methods of life abound; the seal and whale have the limbs modified into flippers, the sloth and squirrel have limbs peculiarly adapted to climbing, while the bats have the fore limbs modeled for flight.

Carnivorous Mammals. — As the word "carnivorous" denotes, these animals are to a large extent flesh eaters. In a wild state they hunt their prey, which is caught and torn with the aid of well-developed claws and long, sharp teeth. These teeth, so well developed in the dog, are known as *canine* teeth or dog teeth. All flesh-eating mammals are wandering hunters in a state of nature;

[1] With the exception of the monotremes.

many, as the bear and lion, have homes or dens to which they retreat. Some (for example, bears and raccoons) live at least part of the time upon berries and fruit. Seals, sea lions, and walruses are adapted to a life in the water. Especially in the seals, the hind limbs are almost useless on land. Some of the fur bearers, as the otter and mink, lead a partially aquatic life. Others in this great group prefer regions of comparative dryness, as the inhabitants of the South African belt. A few have come to live most of their time in the trees, the raccoon being an example. Many have adaptations for food getting and escape from enemies; the seasonal change in color of the weasel is an example of an adaptation which serves both of the above purposes. This is only one of hundreds of others that might be mentioned.

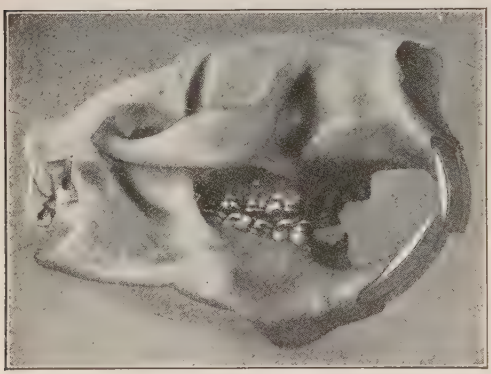
Skull of a dog. Notice the size and shape of the canine teeth.

Economic Importance. — The Carnivora as a group are of much economic importance as the source of most of our fur. The fur seal fisheries alone amount to many millions of dollars annually. Otters, skunks, sables, weasels, and minks are of considerable importance as fur producers. Our domestic cats (particularly deserted cats) are such factors in the extermination of our native birds that their place as house pets is seriously questioned by some people. In India tigers, and in Africa lions, are man-eating in certain localities, and in our own country wolves, pumas, and wild cats do some damage.

The California sea lion (*Zalophus californianus*). Photographed in the Philadelphia Zoölogical Gardens by Davison.

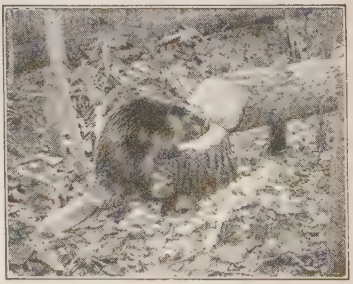
Rodents. — Mammals known as rodents have the teeth so modified that on the upper and lower jaw two prominent incisor teeth can be used for gnawing. These teeth keep their chisel-like

edge because the back part of the teeth is softer and wears away more rapidly. The canine or dog teeth are lacking. We are all familiar with the destructive gnawing qualities of one of the commonest of all rodents, the rat. The common brown rat is an example of a mammal, harmful to civilized man, which has followed in his footsteps all over the world. Starting from China, it spread to eastern Europe, thence to western Europe, and in 1775 it had obtained a lodgment in this country. In seventy-five years it reached the Pacific coast, and is now fairly common all over the United States, being one of the most prolific of all mammals. A determined effort is now being made to exterminate this pest because of its connection with bubonic plague.



Skull of a porcupine, a rodent. Notice the large overlapping incisor teeth. Compare them with the teeth of a dog (see page 313).

Although most rodents may be considered as pests (as the rat and mouse), others are of use to man. Some of this order furnish food to man, as the rabbit, hares, and squirrels. Rabbits, although rapid breeders, are kept in check in most parts of this country by their natural enemies, birds of prey, and flesh-eating mammals. But in Australia, where they were introduced by man, they have become so numerous as to require government action in the form of a bounty for their destruction. Thousands of sheep are starved to death each year because rabbits eat up their pasturage. The fur of the beaver, one of the largest of



Beaver (*Castor canadensis*). North America. Copyright, 1900, by A. Radcliffe Dugmore.

this order, is of considerable value, as are the coats of several other rodents. The fur of the rabbit is used in the manufacture of felt hats. The quills of the porcupines (greatly developed and stiffened hairs) have a slight commercial value.

Virginia deer. From photograph loaned by the American Museum of Natural History.

Ungulates: Hoofed Mammals. — This group includes the domesticated animals, as the horse, cow, sheep, and pig. A group of animals which originally roamed wild, many species eventually came under the subjugating influence of man. Now they form a source of the world's wealth, and are an important part of the wealth of the United States.

The order of ungulates is a very large one. It is characterized by the fact that the nails have grown down to become thickened as hoofs. In some cases only two (the third and fourth) toes are largely developed. Such animals have a cleft hoof, as in the ox, deer, sheep, and pigs. These form the even-toed ungulates. The deer family are the largest in number of species and individuals among our native forms, and in fact the world over. Among them are the common Virginia deer of the Eastern states, the white-tailed deer of our Adirondack forests. The bison, or buffalo, is nearly related to the deer and wild cattle. Formerly bisons existed in enormous

The bison.

numbers on our Western plains. They were hunted by whites and Indians for the hides and tongues only, and thousands of carcasses were left to rot after a hunt. They are now almost extinct.

Geologic History of the Horse. — In some ungulates the middle toe of the foot has become largely developed, with the result that the animal stands on it. Such are the zebra and the horse.

We have, from time to time, made reference to the fact that certain forms of life, now almost extinct, flourished on the earth in former geologic periods. It is interesting to note that America was the original home of the horse, although at the time of the earliest explorers the horse was unknown here, the wild horse of the Western plains having arisen from horses introduced by the Spaniards. Long ages ago, the first ancestors of the horse were probably little animals about the size of a fox. The earliest horse we have knowledge of had four toes on the fore and three toes on the hind feet. Thousands of years later we find a larger horse, the size of a sheep, with a three-toed foot. By gradual changes, caused by the tendency of the animals to vary and by the action of the surroundings upon the animal in preserving these variations, there was eventually produced our present horse, an animal with legs adapted for rapid locomotion, with feet particularly fitted for the life in open fields, and with teeth which serve well to seize and grind herbage.

Domestication of Animals; Breeding by Selection. — The horse, which for some reason disappeared in this country, continued to exist in Europe, and man, emerging from his early savage condition, began to make use of the animal. We know the horse was domesticated in early Biblical times, and that he soon became one of man's most valued servants. In more recent times, man has begun to artificially change the horse by breeding for certain desired characteristics.

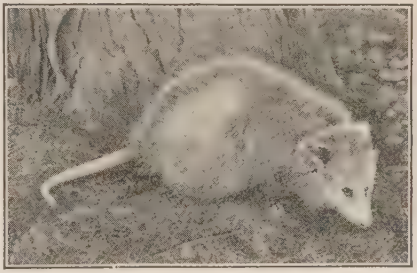
To do this, the horses which have varied so as to show the characters desired by the breeder are selected and bred together. The young from these animals are likely to be like the parents and, because of the tendency of animals to vary, will be even more likely to show the characters the breeder desires than their parents. If this process is repeated for several generations, it will be seen that

man, by *artificial selection*, might have considerably modified the type of horse with which he started. In this manner have been established and improved the various types of horses familiar to us as draft horses, coaches and hackneys, and the trotters. In a similar manner have been obtained the various breeds of cattle, sheep, swine, etc.

It is needless to say that all the various domesticated animals have been tremendously changed in a similar manner since civilized man has come to live on the earth. When we realize the very great amount of money invested in domesticated animals; that there are over 60,000,000 each of sheep, cattle, and swine and over 20,000,000 horses owned in this country, then we may see how very important a part the domestic animals play in our lives.

Other Orders of Mammals. — The lowest are the monotremes, animals which lay eggs like the birds, although they are provided with hairy covering like other mammals. Such are the Australian spiny anteater and the duck mole.

All other mammals bring forth their young developed to a form similar to their own. The kangaroos and opossum, however, are provided with a pouch on the ventral side of the body in which the very immature, blind, and helpless young are nourished until they are able to care for themselves. These pouched animals are called *marsupials*.



Virginia opossum. Photograph, one eighth natural size, by N. F. Davis.

The other mammals, in which the young are born able to care for themselves, and have the form of the adult, may be briefly classified as follows: —

	Character	Examples
Edentates	Toothless or with very simple teeth	Anteater Sloth Armadillo
Rodents	Incisor teeth, chisel-shaped, usually two above and two below	Beaver, rat Porcupine, rabbit Squirrels
Cetaceans	Adapted to marine life, teeth of whales sometimes platelike	Whales Porpoise

Ungulates	Hoofs, teeth, adapted for grinding	(*a*)	Odd-toed
			Horse
			Rhinoceros
			Tapir
		(*b*)	Even-toed
			Ox
			Pig
			Sheep
			Deer
Carnivora	Long canine teeth, sharp and long claws, usually aggressively colored		Dogs
			Cats
			Lions
			Bears, etc.
			Seals and sea lions
Chiroptera	Fore limbs adapted to flight, teeth pointed		Bat
Primates	Erect or nearly so, fore appendage provided with hand		Monkeys
			Apes
			Man

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XXIII. MAN, A MAMMAL

Problem XLI. *A study of man as a vertebrate compared with the frog.* (*Laboratory Manual, Prob. XLI.*)

(*a*) *Comparison of body covering.*

(*b*) *The study of muscles.*

(*c*) *Adaptations in the skeleton.*

(*d*) *Nervous system.*

Man's Place in Nature. — Although we know that man is separated mentally by a wide gap from all other animals, in our study of physiology we must ask where we are to place man. If we attempt to classify man, we see at once he must be placed with the vertebrate animals because of his possession of a vertebral column. Evidently, too, he is a mammal, because the young are nourished by milk secreted by the mother and because his body has at least a partial covering of hair. Anatomically we find that we must place man with the apelike mammals, because of these numerous points of structural likeness. The group of mammals which includes the monkeys, apes, and man we call the *primates*.

Although anatomically there is a greater difference between the lowest type of monkey and the highest type of ape than there is between the highest type of ape and the lowest savage, yet there is an immense mental gap.

Undoubtedly there once lived upon the earth races of men who were much lower in their mental organization than the present inhabitants.

Evolution of Man. — If we follow the early history of man upon the earth, we find that at first he must have been little better than one of the lower animals. He was a nomad, wandering from place to place, living upon whatever living things he could kill with his hands. Gradually he must have learned to use weapons, and thus kill his prey, first using rough stone implements for this purpose. As man became more civilized, implements of bronze and of iron

were used. About this time the subjugation and domestication of animals began to take place. Man then began to cultivate the fields, and to have a fixed place of abode other than a cave. The beginnings of civilization were long ago, but even to-day the earth is not entirely civilized.

The Races of Man. — At the present time there exist upon the earth five races or varieties of man, each very different from the other in instincts, social customs, and, to an extent, in structure. These are the Ethiopian or negro type, originating in Africa; the Malay or brown race, from the islands of the Pacific; the American Indian; the Mongolian or yellow race, including the natives of China, Japan, and the Eskimos; and, finally, the highest type of all, the Caucasians, represented by the civilized white inhabitants of Europe and America.

The Human Body a Machine. — In all animals, and the human animal is no exception, the body has been likened to a machine in that it turns over the *latent* or potential energy stored up in food into *kinetic* energy (mechanical work and heat), which is manifested when we perform work. One great difference exists between an engine and the human body. The engine uses fuel unlike the substance out of which it is made. The human body, on the other hand, uses for fuel the same substances out of which it is formed; it may, indeed, use part of its own substance for food. It must as well do more than purely mechanical work. The human organism must be so delicately adjusted to its surroundings that it will react in a ready manner to stimuli from without; it must be able to utilize its fuel (food) in the most economical manner; it must be fitted with machinery for transforming the energy received from food into various kinds of work; it must properly provide the machine with oxygen so that the fuel will be oxidized, and the products of oxidation must be carried away, as well as other waste materials which might harm the effectiveness of the machine. Most important of all, the human machine must be able to repair itself.

In order to understand better this complicated machine, the human body, let us examine the structure of its parts and thus get a better idea of the interrelation of these parts and of their functions.

Structure of the Skin. — In man, the outer covering of the skin is composed of two layers. The outer part (called the *epidermis*) is composed largely of flattened dead cells. It is part of this layer that peels off after sunburn, or that separates from the inner part of the epidermis when a water blister is formed. The inner cells of the epidermis are provided with more or less pigment or coloring matter. It is to the varying quantity of this pigment that the light or dark complexion is due. The inmost layer of the epidermis is made up of small cells which are constantly dividing to form new cells to take the place of those in the outer layer which are lost.

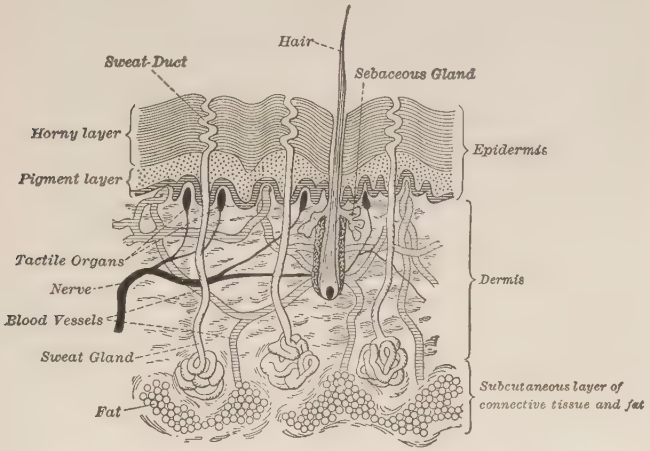


Diagram of a section of the skin. (Highly magnified.)

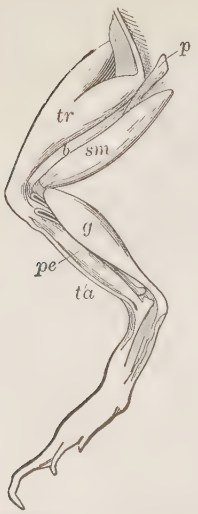
The *dermis*, or inner layer, is largely composed of connective tissue filled with a network of blood vessels and nerves. This layer contains the *sweat glands*, some of the most important glands in the body. Other organs connected with the nervous system, and called the *tactile corpuscles*, cause this part of the skin to be sensitive to touch.

Nails and Hairs. — Nails are a development from the horny layer of the epidermis. A hair is also an outgrowth of the horny layer, although it is formed in a deep pit or depression in the dermis; this pit is called the *hair follicle*.

The Glands of the Skin. — Scattered through the dermis, and usually connected with the hair follicles, are tiny oil-secreting glands, the *sebaceous glands*. The function of the sebaceous gland is to keep the hair and surface of the skin soft. The other glands, known as *sweat glands*, are to be found in profusion, over 2,500,000 being present in the skin of a normal man. These glands carry off certain wastes from the blood in the water they pass off. Thus the skin not only protects the body, but also serves as an excretory organ. Its most important function, however, is the regulation of the heat of the body. How it does this, we shall learn later. (See Chapter XXVII.)

Connective Tissue. — The layer immediately beneath the dermis is known as the *subcutaneous* layer. It is an important storage place for fat. Underneath this layer we find a mass of flesh or *muscle*. Intermixed with this is a considerable amount of fat. The fat, muscle, — in fact, all the tissues in the body, — are held together by fibrous threads called *connective tissue*.

Muscles and Movement. — We are all aware that motion in any of the higher animals is caused by the action of the muscles. These contract to cause movement. In man and the other vertebrate animals, the muscles are almost always fastened to bones, which, acting as levers, give wide range of motion.



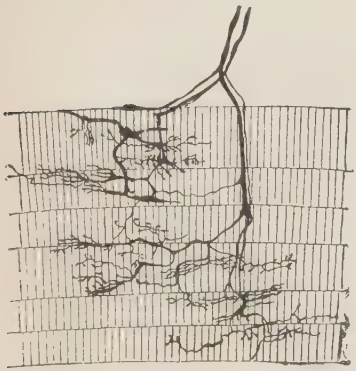
Muscles of the left leg of the frog; *b*, M. biceps; *g*, M. gastrocnemius; *sm*, M. semimembranosus; *tr*, M. triceps.

Arrangement of Voluntary Muscles in the Human Body. — Muscles are usually placed in pairs; one, called the *extensor*, serves to straighten the joint; the other, the *flexor*, bends the joint. Locate, by means of feeling the muscles when expanded and when contracted, the extensors and flexors in your own arm. Use the leg of a frog to determine which muscles are extensors and which flexors (see the Figure). This paired arrangement of muscles is of obvious importance, a flexor muscle balancing the action of an extensor on the other side of the joint. The end of the muscle that has the wider move-

ment in a contraction is called the *insertion;* the part that moves least is the *origin.*

A bit of voluntary muscle fiber, showing the cross striations as seen under the microscope. (Highly magnified.)

Microscopic Structure of Voluntary Muscle. — With a sharp pair of scissors cut through a muscle at right angles to the long axis; examination will show that it is composed of a number of bundles of fibers. These fibers are held together by a sheath of connective tissue. Each of these bundles may be separated into smaller ones. If we continue this so as to separate into the smallest possible bits that can be seen with the naked eye, and then examine such a tiny portion under the compound microscope, it will present somewhat the appearance shown in the Figure. The muscle is seen to be made up of a number of tiny threads which lie side by side, held together by the sheath. Muscles, then, are bundles of long fibers. In man, muscles which are under the control of the will have a striated appearance, while those which are involuntary are unstriated. Both kinds are supplied with nerves, which control them (see Figures).



The delicate endings of nerves in voluntary muscle. (Highly magnified.)

Muscle Tissue and its Uses. — Muscles evidently form a large part of the body, in man, nearly half the body weight being muscle. Nearly every muscle in the human body is attached to a bone either at one or at both ends. Movement is performed by means of the muscles, leverage being obtained by means of their attachment to the bones. Movement is, indeed, the chief function of muscles. In the human body there are over

five hundred muscles, varying from one smaller than a pinhead to a band almost two feet in length. Every movement of the body, be it merely a change of expression or change in the pitch of the voice, directly results from contraction of a muscle. Muscles also give form to the body, and are useful in protecting the delicate organs and large blood vessels within them.

Muscles and the Skeleton. — Muscles would be of little use to animals if they were not attached to hard parts of the body which serve as levers. In many invertebrate animals (for example, crustaceans, insects, and mollusks), the muscles are attached to the exoskeleton. In man they are attached to the endoskeleton.

In the hind leg of the frog, if we cut through the muscles of the thigh to the bone, we may make out exactly how and where the muscles of the thigh are attached to the bone. Moving the leg in as many different directions as possible, we notice that it may be flexed or bent; that it may be extended to its original position; that it may be moved to and from the midline of the body; that, with the knee held stiff, the whole limb may be made to describe the arc of a circle.[1]

Hinge joint, showing muscle (*a*) and its tendon (*b*).

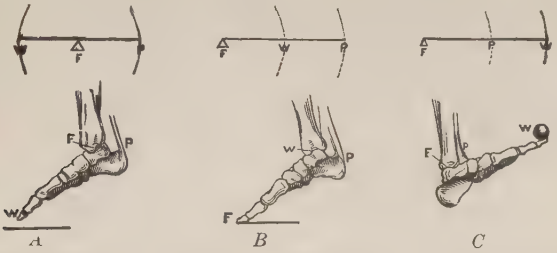
These same movements are possible in the leg of a man. This movement between bones is obtained by means of joints. If, in the frog, we carefully separate the muscles of the thigh to the bone, we find that they are attached to the bone by white, glistening *tendons*. Careful examination shows that the bones themselves are held together by very tough white bands or cords; these are the *ligaments*. We find, too, that one end of the large thigh bone fits into a socket in the hip bone or pelvic arch. It is thus easy to see how such free movement is obtained in the leg.

Levers in the Body. — It is evident that movement of a joint is caused by muscles which act in coöperation with the bones to which they are attached; the latter thus form true levers. A lever is a structure by which either *greater work power* or *greater range of motion* is obtained. In this apparatus, the lever works against a fixed point, the fulcrum, in order to raise a certain weight. A seesaw is a lever; here the fulcrum is in the middle, the weight is at one end, and the power to lift the weight is applied at the other end. There are three classes of levers, named according to the position of the fulcrum.

In the first class, the fulcrum lies between the weight and the power;

[1] At this point demonstration with a human skeleton should be made.

the seesaw is an example of this. The best example in the human body of a lever of the first class is seen when the head nods. Here the fulcrum is the vertebra known as the *atlas;* the power is the muscles of the neck attached to the back of the skull and to the spine; the weight is the front part of the head. When one keeps the head erect, this lever is used; the nodding head when one is napping shows this plainly.

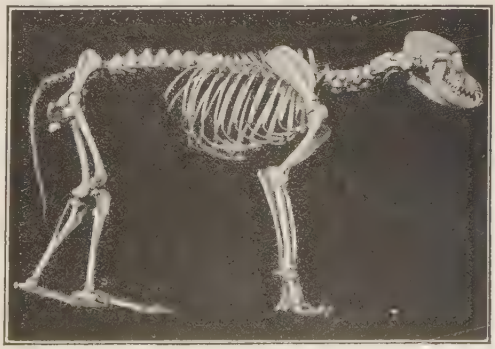


Three classes of levers. *A*, a lever of the first class; *B*, a lever of the second class; *C*, a lever of the third class. (See text.)

A lever of the second class has the fulcrum at one end, and the weight between it and the power; when we rise on our toes, we use this kind of lever.

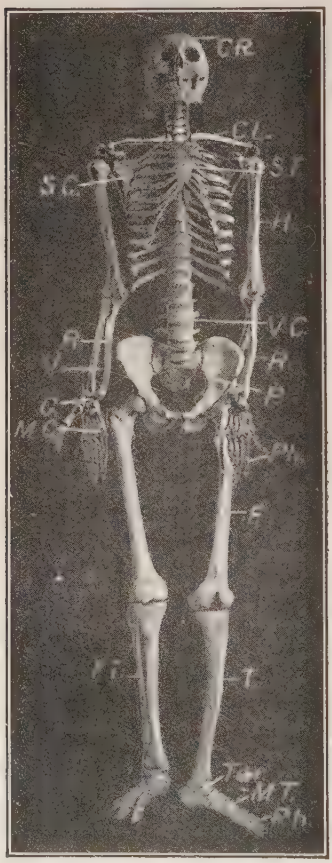
In a lever of the third class, the fulcrum is at one end, with the power between it and the weight. This is the kind of lever seen most frequently in the human body. The flexing (drawing up) of the lower leg or the forearm is an example of the use of this kind of lever. In such a lever, a wide range of movement is obtained.

General Structure and Uses of the Skeleton. — Evidently bones form a framework to which muscles are attached; thus they are used as levers for purposes of movement. Second, they give protection to delicate organs; they form a case around the brain and spinal cord; as ribs they protect the organs in the body cavity. Third, they give rigidity and form to the body.



The skeleton of a dog; a typical mammal.

The skeleton of vertebrate animals consists of two distinct regions: a *vertebral column* of backbone which, with the skull, forms the *axial* skeleton; and the parts attached to this main axis, the *appendicular* skeleton (the appendages). All skeletons of vertebrates have the same general regions, the size and shape of the bones in these regions differing somewhat in each kind of animal.

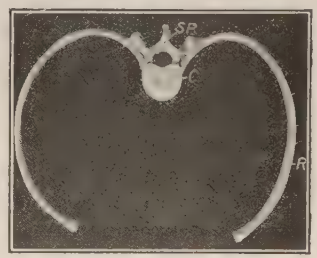


Skeleton of man: *CR*, cranium; *CL*, clavicle; *ST*, sternum; *SC*, scapula; *H*, humerus; *VC*, vertebral column; *R*, radius; *U*, ulna; *P*, pelvic girdle; *C*, carpals; *MC*, metacarpals; *Ph*, phalanges; *F*, femur; *Fi*, fibula; *T*, tibia; *Tar*, tarsals; *MT*, metatarsals.

In the axial skeleton of the frog, as well as in man, the vertebral column is made up of a number of bones of irregular shape, which fit more or less closely into each other. These bones are called *vertebræ*. Notice that the vertebræ possess long processes to which muscles of the back are attached. Certain of the vertebræ bear ribs (arched, flat bones), the special function of which is to protect the organs of the upper body cavity.

Adaptations in the Vertebral Column. — The vertebral column in man is made up of many separate pieces of bone: thirty-three in a child; twenty-six in the adult, several bones in the region of the pelvis later growing together. Each vertebra presents the general form of a body or centrum of bone and a bony arch with seven projections; in this arch runs the spinal cord. The surface of the centrum and those parts of the vertebræ, each of which fits into its next neighbor, are covered with pads of cartilage. Two of the processes in each vertebra project forward and two back-

ward; these form articulations or joints with the neighboring vertebræ. Of the other processes, one projects dorsally and two project laterally; these give attachment to the muscles of the back. The two vertebræ directly beneath the head are modified so as to permit the skull to rest in the upper one; this articulates freely with the second vertebra, thus permitting of the nodding and turning movements of the head. Besides these individual adaptations, the vertebral column, as a whole, is peculiarly adapted to protect the brain from jar; this is seen in the double bend of the vertebral column and the pads of cartilage between the individual vertebræ. The whole column of vertebræ joined each to the other supports the weight of the body. The largest vertebræ at the base are joined to the huge pelvic bones for the better support of the body above. That part of the vertebral column of man which bears the ribs is known as the *thoracic region*. The ribs, twelve in number, are long, curved bones which combine lightness with strength; joined by elastic cartilage to the sternum in front and to the vertebræ behind, they form a wonderful protection to the organs in the thoracic cavity, and yet allow free movement in breathing.

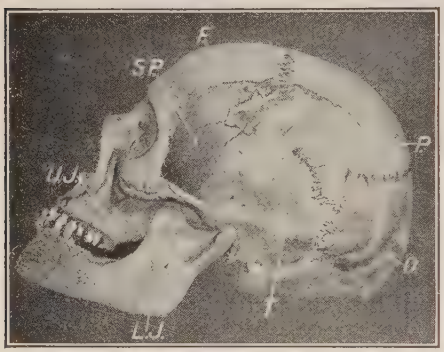


Vertebra, showing attachment of ribs; *C*, centrum; *R*, ribs; *SP*, spinous process.

The Appendages. — The parts of the skeleton to which the bones of the anterior and posterior appendages are attached are respectively known as the *pectoral girdle* (from which hangs the arm) and the *pelvic girdle* (which joins the leg bones to the axial skeleton).

The bones of the appendages attached to the pectoral and pelvic girdles are adapted peculiarly to locomotion and support; for this purpose the bones are long and strong, hinged by very flexible joints. The latter are especially free in the hand to allow for grasping. In the leg, where weight must be supported as well as carried, the bones are bound more firmly to the axial skeleton. The bones of the foot are so arranged that a springy arch is formed which aids greatly in locomotion.

The Human Skull. — The skull shows wonderful adaptations for its varied functions. The brain case is compactly built, its arched roof giving strength. The eye and inner ear are protected in sockets of bone. The lower jaw works upon a hinge, and furnishes attachment for strong muscles which move the jaw.



The skull: *F.*, frontal bone; *P.*, parietal bone; *T.*, temporal bone; *SP.*, sphenoid bone; *O.*, occipital bone; *U.J.*, superior maxillary (upper jaw) bone; *L.J.*, inferior maxillary (lower jaw) bone.

The skeleton, besides the purposes already described, protects certain organs in the body cavity of man.

Other Organs. — We have seen that a body cavity has developed in all animals which are more complex than the baglike hydra, and that a food tube has come to lie within this space. In all such animals the structures which have to do with digestion and absorption of food, most of the structures which have to do with the circulation of this food and of the blood, and organs which give oxygen to the blood, as well as the organs of excretion and of reproduction, lie within the body cavity. These organs we shall discuss in detail later.

Nerves. — Other structures, known as nerves, are found in practically all parts of the body. We find that nerves have their endings in the skin, in muscle, and in the cells of glands in various parts of the body; we find a nerve supply to the heart, lungs, and other structures within the body cavity. The most important part of the nervous system in vertebrate animals lies within the cavity formed by bones making up the skull and the vertebral column. This central nervous system, the *spinal column* and the *brain*, is a characteristic of the vertebrate animals.

General Functions of the Nervous System. — We have seen that, in the simplest of animals, one cell performs the functions necessary to its existence. In the more complex animals, where groups of cells form tissues, each having a different function, a nervous system is developed. *The functions of the human nervous system are:*

(1) *the providing of man with sensation, by means of which he gets in touch with the world about him;* (2) *the connection of organs in different parts of the body so that they act as a united and harmonious whole;* (3) *the giving to the human being a will, a provision for thought.* Coöperation in word and deed is the end attained. We are all familiar with examples of the coöperation of organs. You see food; the thought comes that it is good to eat; you reach out, take it, raise it to the mouth; the jaws move in response to your will; the food is chewed and swallowed; while digestion and absorption of the food are taking place, the nervous system is still in control. The nervous system also regulates pumping of blood over the body, respiration, secretion of glands, and, indeed, every bodily function. Man is the highest of all animals because of the extreme development of the nervous system. Man is the thinking animal, and as such is master of the earth.

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XXIV. FOODS AND DIETARIES

Problem XLII. *A study of food values and diets.* (*Laboratory Manual, Prob. XLII.*)

(*a*) *Food values and cost.*

(*b*) *Nutritive values as compared with cost.*

(*c*) *The family dietary.*

(*d*) *Food values.*

Why we need Food. — *We have already defined food as anything that forms material for the growth or repair of the body of a plant or animal, or that furnishes energy for it.* The millions of cells of which the body is composed must be given material which will form more living matter or material which can be oxidized to release energy when muscle cells move, or gland cells secrete, or brain cells think. Food, then, not only furnishes our body with material to grow, but also gives us the energy we expend in the acts of walking, running, breathing, and even in thinking.

Nutrients. — Certain nutrient materials form the basis of food of both plants and animals. These have been stated to be *proteids* (such as lean meat, eggs, the gluten of bread), *carbohydrates* (starches, sugars, gums, etc.), *fats* and *oils* (both animal and vegetable), and *mineral matter* and *water*. The parts of the human body, be they muscle, blood, nerve, bone, or gristle, are built up from the nutrients in our food.

Proteids. — Proteids, in some manner unknown to us, are manufactured in the bodies of green plants. Proteid substances contain the element nitrogen. Hence such foods are called nitrogenous foods. Man must form the protoplasm of his body (that is, the muscles, tendons, nervous system, blood corpuscles, the living parts of the bone and the skin, etc.) from nitrogenous food. Some of this he obtains by eating the flesh of animals, and some he obtains directly from plants (for example, peas and beans). Because of their chemical composition, proteids are considered to

be flesh-forming foods. They are, however, oxidized to release energy if occasion requires it.

Fats and Oils. — Fats and oils, both animal and vegetable, are the materials from which the body derives part of its energy. The chemical formula of a fat shows that, compared with other food substances, there is very little oxygen present; hence the greater capacity of this substance for uniting with oxygen. The rapid burning of fat compared with the slower combustion of a piece of meat or a piece of bread illustrates this. A pound of butter releases over twice as much energy to the body as does a pound of sugar or a pound of steak. Human fatty tissue is formed in part from fat eaten, but carbohydrate or even proteid food may be changed and stored in the body as fat.

Carbohydrates. — We see that the carbohydrates, like the fats, contain carbon, hydrogen, and oxygen. Here, however, the oxygen and hydrogen are united in the molecule in the same proportion as are hydrogen and oxygen in water. *Carbohydrates are essentially energy-producing foods.* They are, however, of use in building up or repairing tissue. It is certainly true that in both plants and animals, such foods pass directly, together with foods containing nitrogen, to repair waste in tissues, thus giving the needed proportion of carbon, oxygen, and hydrogen to unite with the nitrogen in forming the protoplasm of the body.

Inorganic Foods. — Water forms a large part of almost every food substance. The human body, by weight, is composed of about 60 per cent water. It is used to make the blood, and a sufficient quantity is most essential to health. When we drink water, we take with it some of the inorganic salts used by the body in the making of bone and in the formation of protoplasm. Sodium chloride (table salt), an important part of the blood, is taken in as a flavoring upon our meats and vegetables. Phosphate of lime and potash are important factors in the formation of bone.

Phosphorus is a necessary substance for the making of living matter, milk, eggs, meat, whole wheat, and dried peas and beans containing small amounts of it. Iron also is an extremely important mineral, for it is used in the building of red blood cells. Meats, eggs, peas and beans, spinach and prunes, are foods containing some iron.

Some other salts, compounds of calcium, magnesium, potassium, and

phosphorus, have been recently found to aid the body in many of its most important functions. The beating of the heart, the contraction of muscles, and the ability of the nerves to do their work appear to be due to the presence of minute quantities of these salts in the body.

Uses of Nutrients. — The following table sums up the uses of nutrients to man: [1] —

Proteid . . . . . White (albumen) of eggs, curd (casein) of milk, lean meat, gluten of wheat, etc.	Forms tissue (muscles, tendon, and probably fat).	All serve as *fuel* and yield *energy* in form of heat and muscular strength.
Fats . . . . . Fat of meat, butter, olive oil, oils of corn and wheat, etc.	Form fatty tissue.	
Carbohydrates . . . . . Sugar, starch, etc.	Transformed into fat.	
Mineral matters (ash). . . . Phosphates of lime, potash, soda, etc.	Aid in forming bone, assist in digestion, etc.	

How the Exact Nutritive Value of Food has been Discovered. — For a number of years, experiments have been in progress in different parts of the civilized world which have led to the beliefs regarding food just quoted. One of the most accurate and important series of experiments was made a few years ago by the late Professor W. O. Atwater of Wesleyan University, in coöperation with the United States Department of Agriculture. By means of a machine called the *respiration calorimeter* (Latin, *calor* = heat + *metrum* = measure), which measures both the products of respiration and the heat given off by the body, it has been possible to determine accurately the value of different kinds of food, both as fuel and as tissue builders. This respiration calorimeter is described by Professor Atwater as follows: —

" Its main feature is a copper-walled chamber 7 feet long, 4 feet wide, and 6 feet 4 inches high. This is fitted with devices for maintaining and measuring a ventilating current of air, for sampling and analyzing this air, for removing and measuring the heat given off within the chamber, and for passing food and other articles in and out. It is furnished with a folding bed, chair, and table, with scales and appliances for muscular work, and has telephone connection with the outside. Here the subject stays for a period of from three to twelve days, during which time, careful analyses and measurements are made of all material which enters the body in the food, and of that which leaves it in the breath and excreta.

[1] W. O. Atwater, *Principles of Nutrition and Nutritive Value of Food*, U.S. Department of Agriculture, 1902.

Record is also kept of the energy given off from the body as heat and muscular work. The difference between the material taken into and that given off from the body is called the *balance of matter*, and shows whether the body is gaining or losing material. The difference between the energy of the food taken and that of the excreta and the energy given off by the body as heat and muscular work, is the balance of energy, and, if correctly measured, should equal the energy of the body material gained or lost. With such apparatus it is possible to learn what effect different conditions of nourishment will have on the human body. In one experiment, for instance, the subject might be kept quite at rest, and in the next do a certain amount of muscular or mental work with the same diet as before, then by comparing the results of the two, the use which the body makes of its food under the different conditions could be determined; or the diet may be slightly changed in the one experiment, and the effect of this on the balance of matter or energy, observed. Such methods and apparatus are very costly in time and money, but the results are proportionately more valuable than those from simpler experiments."

Fuel Values of Nutrients. — In experiments performed by Professor Atwater and others, and in the appended tables, the value of food as a source of energy is stated in heat units called *calories*. *A Calorie*[1] (*large calorie*) *is the amount of heat required to raise the temperature of one kilogram of water from zero to one degree Centigrade*. This is about equivalent to raising one pound four degrees Fahrenheit. The fuel value of different foods may be computed in a definite manner. This is done by burning a given portion of a food (say one pound) in the apparatus known as a *calorimeter*.

The Best Dietary. — Inasmuch as all living substance contains nitrogen, it is evident that proteid food must form a part of the dietary; but proteid alone is not usable. If more proteid is eaten than the body requires, then immediately the liver and kidneys have to work overtime to get rid of the excess of proteid which forms a poisonous waste harmful to the body. We must take foods that will give us, as nearly as possible, the proportion of the different chemical elements as they are contained in protoplasm. It has been found, as a result of studies of Atwater and others, that a man who does muscular work requires a little less than one quarter of a pound of proteid, the same amount of fat, and about one pound

[1] It is customary in works on nutrition to use the term "calorie," spelled with a small initial c, to mean the large calorie. It is so used in this text.

of carbohydrate to provide for the growth, waste, and repair of the body and the energy used up in one day. Put in another way, Atwater's standard for a man at light exercise is food enough to yield 2816 calories; of these, 410 calories are from proteid, 930 calories from fat, and 1476 calories from carbohydrate. That is, for every 100 calories furnished by the food, 14 are from proteid, 32 from fat, and 54 from carbohydrate. In exact numbers, the day's ration as advocated by Atwater would contain about 100 grams or 3.7 ounces proteid, 100 grams or 3.7 ounces fat, and 360 grams or 13 ounces carbohydrate. Professor Chittenden of Yale University, another food expert, thinks we need proteids, fats, and carbohydrates in about the proportion of 1 to 3 to 6, thus differing from Atwater in giving less proteid in proportion. Chittenden's standard for the same man is food to yield a total of 2360 calories, of which proteid furnishes 236 calories, fat 708 calories, and carbohydrates 1416 calories. For every 100 calories furnished by the food, 10 are from proteid, 30 from fat, 60 from carbohydrate. In actual amount the Chittenden diet would contain 2.16 ounces proteid, 2.83 ounces fat, and 13 ounces carbohydrate.[1] A German named Voit gives as ideal 25 proteids, 20 fat, 55 carbohydrate, out of every 100 calories; this is nearer our actual daily ration. In addition, an ounce of salt and nearly one hundred ounces of water are used in a day. By means of the table on the following page (from Atwater [2]), which shows the composition of some food materials, the nutritive and fuel value of the foods may be seen at a glance. The amount of *refuse* contained in foods (such as the bones of meat or fish, the exoskeleton of crustaceans and mollusks, the woody coverings of plant cells) is also shown in this table.

A Mixed Diet Best. — Knowing the proportion of the different food substances required by man, it will be an easy matter to determine from this table the best foods for use in a mixed diet. Meats contain too much nitrogen in proportion to the other substances. In milk, the proportion of proteids, carbohydrates, and fats is nearly right to make protoplasm; a considerable amount of

[1] Page 18, Bul. 6, Cornell Reading Course.

[2] W. O. Atwater, *Principles of Nutrition and Nutritive Value of Food*, U.S. Department of Agriculture, 1902.

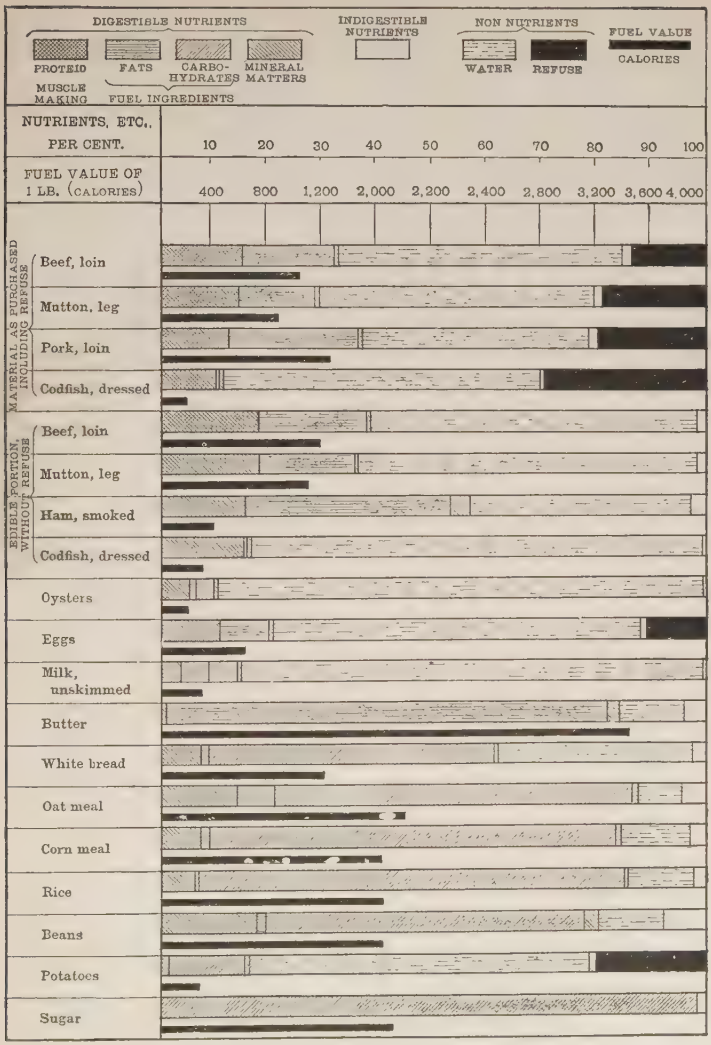
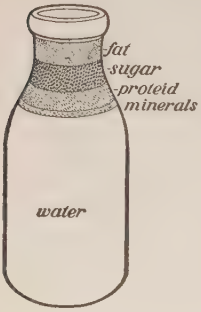
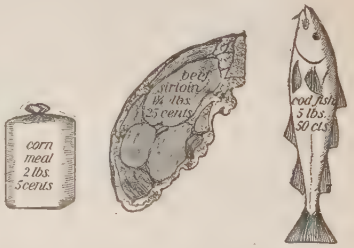


Table of food values. Determine the percentage of water in codfish, loin of beef, milk, potatoes. Percentage of refuse in leg of mutton, codfish, eggs, and potatoes. What *is* the refuse in each case? Find three foods containing a high percentage of proteid; of fat; of carbohydrate. Find some food in which the proportions of proteid, fat, and carbohydrate are combined in the right proportions.

mineral matter being also present. For these reasons, milk is extensively used as a food for children, as it combines food material for the forming of protoplasm with mineral matter for the building of bone. Some vegetables (for example, peas and beans) contain the nitrogenous material needed for protoplasm formation in considerable proportions, but in a less digestible form than is found in some other foods. Vegetarians, then, are correct in theory when they state that a diet of vegetables may contain everything necessary to sustain life. But a mixed diet is healthier. A purely vegetable diet contains much waste material, such as the cellulose forming the walls of the plant cells, which is indigestible. The Japanese army ration consists almost entirely of rice. A recent report by their surgeon-general intimates that the diminutive stature of the Japanese may, in some part at least, be due to this diet.



The composition of a bottle of milk. Why is it considered a good food?



Three portions of foods, each of which furnishes about the same amount of nourishment.

The Relation of Work to Diet. — It has been shown experimentally that a man doing hard, muscular work needs more food than a person doing light work. The mere exercise gives the individual a hearty appetite; he eats more and needs more of all kinds of food than a man or boy doing light work. Especially is it true that the person of sedentary habits, who does brain work, should be careful to eat less food and food that will digest easily. His proteid food should also be reduced. Rich or hearty foods may be left for the man who is doing hard manual labor out of doors, for any extra work put on the digestive organs takes away just so much the ability of the brain to do its work.

The Relation of Environment to Diet. — We are all aware of the fact that the body seems to crave heartier food in winter than in summer. The temperature of the body is maintained at 98½° in winter as in summer, but much more heat is lost from the body in the cold weather. Hence feeding in winter should be for the purpose of maintaining our fuel sup-

ply. We need heat-producing food, and we need *more* food in winter than in summer, the latter partly because we exercise more in winter. We may use carbohydrates for this purpose, as they are economical and digestible. The inhabitants of cold countries get their heat-releasing foods largely from fats, because no plants are produced there. In tropical countries and in hot weather little proteid should be eaten and a considerable amount of fresh fruit used.

Food Economy. — The American people are far less economical in their purchase of food than most other nations. Nearly one half of the total income of the average workingman is spent on food. Not only does he spend a large amount on food, but he wastes money in purchasing the wrong kinds of food. A comparison of the daily diets of persons in various occupations in this and other countries show that as a rule we eat more than is necessary to supply the necessary fuel and repair, and that our workingmen eat more than those of other countries. Another waste of money by the American is in the false notion that a large proportion of the daily dietary should be meat. Many people think that the most expensive cuts of meat are the most nutritious. The falsity of this idea may be seen by a careful study of the table on page 338, compiled by Atwater, which shows the relative amount of various foods purchasable for 10 cents (present-day prices are from 20 per cent to 50 per cent higher than here quoted).

Daily Fuel Needs of the Body. — It has been pointed out that the daily diet should differ widely according to age, occupation, time of year, etc. The following table shows the daily fuel needs for several ages and occupations: —

Daily Calorie Needs (Approximately)

Obs.		
1.	For child under 2 years	900 calories
2.	For child from 2–5 years	1200 calories
3.	For child from 6–9 years	1500 calories
4.	For child from 10–12 years	1800 calories
5.	For child from 12–14 (woman, light work also)	2100 calories
6.	For boy (12–14), girl (15–16), man sedentary	2400 calories
7.	For boy (15–16) (man, light muscular work)	2700 calories
8.	For man, moderately active muscular work	3000 calories
9.	For farmer (busy season)	3200 to 4000 calories
10.	For ditchers, excavators, etc.	4000 to 5000 calories
11.	For lumbermen, etc.	5000 and more calories

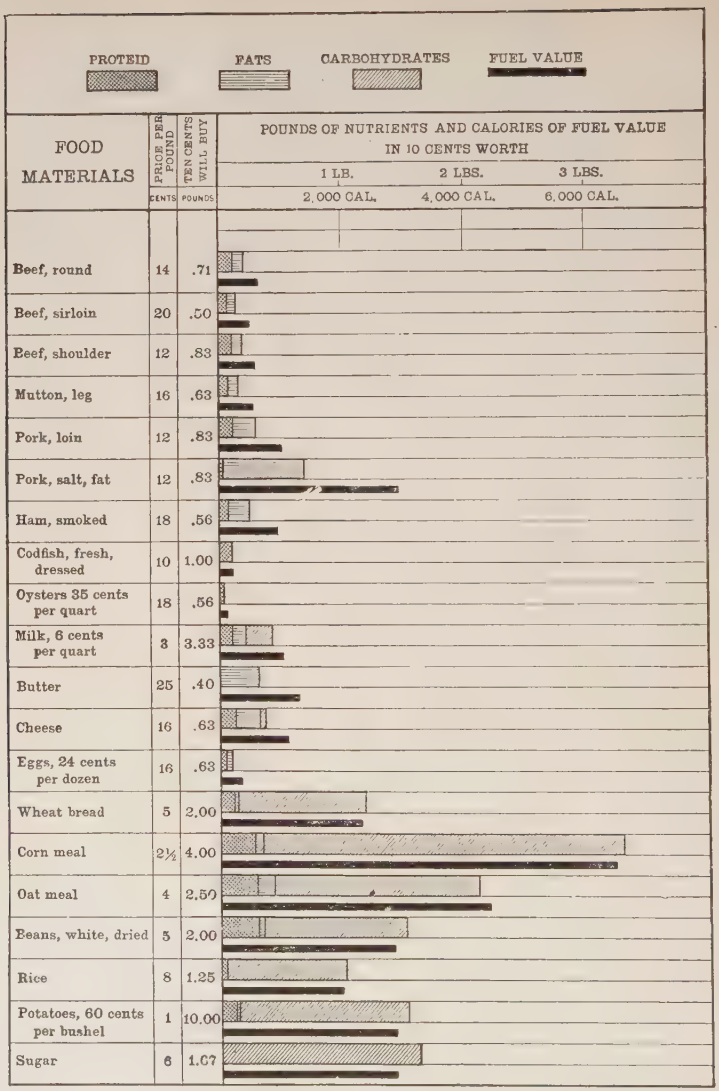


Table showing the cost of various foods. Using this table, make up an economical dietary for one day, three meals, for a man doing moderate work. Give reasons for the amount of food used and for your choice of foods. Make up another dietary in the same manner, using expensive foods. What is the difference in your bill for the day?

This table was worked out from a knowledge that different amounts of energy are released by the body at different times and under differing conditions.

Normal Heat Output. — The following table gives the result of some experiments made to determine the hourly and daily expenditure of energy of the average normal grown person when asleep and awake, at work or at rest.

AVERAGE NORMAL OUTPUT OF HEAT FROM THE BODY

CONDITIONS OF MUSCULAR ACTIVITY	AVERAGE CALORIES PER HOUR
Man at rest, sleeping	65 calories
Man at rest, awake, sitting up	100 calories
Man at light muscular exercise	170 calories
Man at moderately active muscular exercise	290 calories
Man at severe muscular exercise	450 calories
Man at very severe muscular exercise	600 calories

It is very simple to use such a table in calculating the number of calories which are spent in twenty-four hours under different bodily conditions. For example, suppose the case of a clerk or schoolteacher leading a relatively inactive life, who

sleeps for 9 hours	× 65 calories =	585
works at desk 9 hours	× 100 calories =	900
reads, writes, or studies 4 hours	× 100 calories =	400
walks or does light exercise 2 hours	× 170 calories =	340
		2225

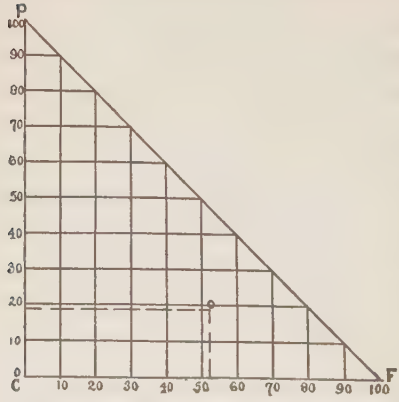
This comes out, as we see, very close to example 6 of the table[1] on page 337.

How we may find whether we are eating a Properly Balanced Diet. — We already know approximately our daily calorie needs and about the proportion of proteid, fat, and carbohydrate needed. Dr. Irving Fisher of Yale University has worked out a very easy method of determining whether one is living on a proper diet. He

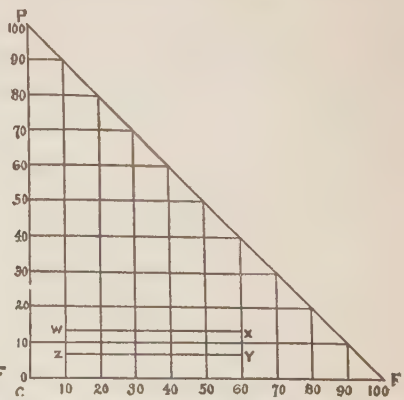
[1] The above tables and those which follow have been taken from the excellent pamphlet of the Cornell Reading Course, No. 6, *Human Nutrition.*

has made up a number of tables, a portion of which follow,[1] in which he has designated portions of food, each of which furnishes 100 calories of energy. The tables show the proportion of proteid, fat, and carbohydrate in each food, so that it is a simple matter by using such a table to estimate the proportions of the various nutrients in our dietary. We may depend upon taking somewhere near the proper amount of food if we take a diet based upon either Atwater's, Chittenden's, or Voit's standard. One of the most interesting and useful pieces of home work that you can do is to estimate your own personal dietary, using the tables giving the 100 calorie portion to see if you have a properly balanced diet. From the table on page 342 make out a simple dietary for yourself, estimating your own needs in calories and then picking out 100 calorie portions of food which will give you the proper proportions of proteid, fat, and carbohydrate.

A Graphic Method of Determining Food Values.[2] — Another method to be used in the laboratory or at home is shown below. Suppose we take any food from our table, — for example, milk. In the triangle at the left, the line *PC* represents the proteid value of a given food, the line *CF* repre-



A food map, the composition of milk being represented by the point *O*.



Food map showing the normal rectangle.

[1] For more complete tables see *Laboratory Manual, Prob. XLII.* They were compiled by Dr. Irving Fisher of Yale University, and are reproduced from the *Journal of the American Medical Association*, Vol. XLVIII, page 16.

[2] See Irving Fisher, "New Methods for indicating Food Values," *American Journal of Physiology*, Vol. XL, No. 1, and "A Graphical Method in Practical Dietetics," *Journal of the American Medical Association*, Vol. XLIII, pages 1316–1324.

senting its fat value; F and P represent 100 per cent fat and proteid respectively.

The threefold constitution of any particular food may be represented graphically by the position of a point O in this triangle. Thus the point O representing milk is located at a height above CF 19 per cent of the total height of PC, which shows that 19 per cent of the food value of milk is proteid; and at a distance to the right of CP towards F, 52 per cent of the distance, signifying that 52 per cent of the food value of milk is fat.

In the triangle at the right, the rectangle $wxyz$ is known as the *normal rectangle*, and shows where a well-balanced food or combination of foods would be approximately located.

Two or more foods may be plotted as follows: The combination of portions equal in calorie value is represented by a point midway between them. If the portions are unequal, the point O will, of course, be proportionally nearer the point locating the larger portion. Likewise, when three foods are combined, the point is first located for two, then this with the third, the resulting combination with the fourth, etc.

Thus we can demonstrate to the eye the value of various foods or combinations of food in a dietary. (For laboratory directions, see *Laboratory Manual, Prob. XLII.*)

Food Waste in the Kitchen. — Much loss occurs in the improper cooking of foods. Meats especially, when overdone, lose much of their flavor and are far less easily digested than when they are cooked rare. The chief reasons for cooking meats are that the muscle fibers may be loosened and softened, and that the bacteria or other parasites in the meat may be killed by the heat. The common method of frying makes foods less digestible. Stewing is an economical as well as healthful method. A good way to prepare meat, either for stew or soup, is to place the meat, cut in small pieces, in cold water, and allow it to simmer for several hours. Rapid boiling toughens the muscle fibers by the too rapid coagulation of the albuminous matter in them, just as the white of egg becomes solid when heated. Boiling and roasting are excellent methods of cooking meat. In order to prevent the loss of the nutrients in roasting, it is well to baste the meat frequently; thus a crust is formed on the outer surface of the meat, which prevents the escape of the juices from the inside.

Vegetables are cooked in order that the cells containing starch grains may be burst open, thus allowing the starch to be more easily attacked by the digestive fluids. Inasmuch as water may dissolve

TABLES OF FOOD VALUES, UNITS AND PRICES

NAME OF FOOD	PORTION CONTAINING 100 FOOD UNITS	WEIGHT OF 100 CALORIES	CALORIES FURNISHED BY			PRICE PER POUND
			Prot.	Fat	Carbo.	
1. *Vegetable*		*Ounces*				*Cents*
Crackers	2 crackers	.9	10	20	70	12
Wheat bread	Thick slice	1.3	9	7	84	5
Corn meal	Cereal dish	.96	10	5	85	4
Oatmeal	1½ servings	5.6	18	7	75	7.5
Beans (baked)	Side dish	2.66	21	18	61	6
Rice	Cereal dish	3.1	10	1	89	10
Sugar	3 teaspoons	.86	—	—	100	6
Potatoes (boiled)	1 large size	3.62	11	1	88	1.5
Cabbage	4 servings	11	20	8	72	2.5
Tomatoes	4 average servings	15.2	21	7	72	6
Lettuce	5 average servings	18	25	14	61	10
2. *Animal*						
Beef (sirloin)	Small steak	1.4	31	69	—	30
Brisket	Ordinary serving	1.80	42	58	—	8
Mutton (leg)	Large serving	1.2	35	65	—	16
Pork (loin)	Small serving	.97	18	82	—	15
Ham	Ordinary serving	1.1	28	72	—	22
Veal (leg)	Large serving	2.4	73	27	—	18
Chicken	Large serving	3.2	79	21	—	24
Codfish	2 servings	4.9	95	5	—	15
Oysters	1 dozen	6.8	49	22	29	25
Lobster	2 servings	4.1	78	20	2	35
Eggs	1 large egg	2.1	32	68	—	25
3. *Dairy Products*						
Whole milk	Small glass	4.9	19	52	29	4
Buttermilk	1½ glass	9.7	34	12	54	2
Butter	Small pat	0.44	0.5	99.5	—	30
Cheese (Amer.)	1½ cubic inch	.77	25	73	2	18
4. *Fruits, nuts, etc.*						
Bananas	1 large	3.5	5	5	90	7
Oranges	1 large	9.4	6	3	91	7
Watermelon	1 whole	27.0	6	6	88	3
Apples	2	7.3	3	7	90	1.5
Peanuts	13	.62	20	63	17	5
Chocolate	⅓ square	.56	8	72	20	40

out nutrients from vegetable tissues, it is best to boil them rapidly in a small amount of water. This gives less time for the solvent action to take place. Vegetables should be cooked with the outer skin left on when it is possible.

Problem XLIII. *A study of some forms of food adulterations.* (*Laboratory Manual, Prob. XLIII.*)

Adulterations in Foods. — The addition of some cheaper substance to a food, with the view to cheating the purchaser, is known as *adulteration*. Many foods which are artificially manufactured have been adulterated to such an extent as to be almost unfit for food or even harmful. One of the commonest adulterations is the substitution of grape sugar (glucose) for cane sugar. Most cheap candy is so made. Flour and other cereal foods are sometimes adulterated with some cheap substitutes, as bran or sawdust. Probably the food which suffers most from adulteration is milk, as water can be added without the average person being the wiser. By means of an inexpensive instrument known as a *lactometer*, this cheat may easily be detected. In most cities, the milk supply is carefully safeguarded, because of the danger of spreading typhoid fever (see Chapter XXIX) from impure milk. Milk is often treated with preservatives which kill the bacteria in it and prevent the milk from souring rapidly. Such preservatives are often harmful to health.

Coffee, cocoa, and spices are subject to great adulteration; cottonseed oil is often substituted for olive oil; butter is too frequently artificial; while honey, sirups of various kinds, cider and vinegar, have all been found to be either artificially made from cheaper substitutes or to contain such substitutes.

Pure Food Laws. — Thanks to the National Pure Food Law passed by Congress in 1907, and to the activity of various city and state boards of health, the opportunity to pass adulterated foods on the public is greatly lessened.

Impure Water. — Great danger comes from drinking impure water. This subject has already been discussed under Bacteria, where it was seen that the spread of typhoid fever in particular is due to a contaminated water supply. As citizens we must aid all

legislation that will safeguard the water used by our towns and cities. Boiling water for ten minutes or longer will render it safe from all organic impurities.

Stimulants. — We have learned that food is anything that supplies building material or releases energy in the body; but some materials used by man, presumably as food, do not come under this head. Such are tea and coffee. When taken in moderate quantities, they produce a temporary increase in the vital activities of the person taking them. This is said to be a stimulation; and material taken into the digestive tract, producing this, is called a *stimulant*. In moderation, tea and coffee appear to be harmless. Some people, however, cannot use either without ill effects, even in small quantity. It is the *habit* formed of relying upon the stimulus given by tea or coffee that makes them a danger to man. In large amounts, they are undoubtedly injurious because of a stimulant called *caffeine* contained in them. Cocoa and chocolate, although both contain a stimulant like caffeine, are in addition good foods, having from 12 per cent to 21 per cent of proteid, from 29 per cent to 48 per cent fat, and over 30 per cent carbohydrate in their composition.

Is Alcohol a Food? — The question of the use of alcohol has been of late years a matter of absorbing interest and importance among physiologists. A few years ago Dr. Atwater performed a series of very careful experiments by means of the respiration calorimeter, to ascertain whether alcohol is of use to the body as food.[1] In these experiments the subjects were given, instead of their daily allotment of carbohydrates and fats, enough alcohol to supply the same amount of energy that these foods would have given. The amount was calculated to be about two and one half ounces per day, about as much as would be contained in a bottle of light wine.[2] This alcohol was administered in small doses six times during the day. Professor Atwater's results may be summed up briefly as follows: —

[1] Alcohol is made up of carbon, oxygen, and hydrogen. It is very easily oxidized, but it cannot, as is shown by the chemical formula, be of use to the body in tissue building, because of its lack of nitrogen.

[2] Alcoholic beverages contain the following proportions of alcohol: beer, from 2 to 5 per cent; wine, from 10 to 20 per cent; liquors, from 30 to 70 per cent. Patent medicines frequently contain as high as 60 per cent alcohol. (See page 350.)

1. The alcohol administered was almost all oxidized in the body.
2. The potential energy in the alcohol was transformed into heat or muscular work.
3. The body did about as well with the rations including alcohol as it did without it.

The committee of fifty eminent men appointed to report on the physiological aspects of the drink problem reported that a large number of scientific men state that they are in the habit of taking alcoholic liquor in small quantities, and many report that they do not feel harm thereby. A number of scientists seem to agree that within limits alcohol may be a kind of food, although a very *poor* food.

On the other hand, we know that although alcohol may technically be considered as a food, it is a very unsatisfactory food and, as the following statements show, it has an effect on the nervous system which foods do not have.

Alcohol a Poison. — *A commonly accepted definition of a poison is that it is any substance which, when taken into the body, tends to cause serious detriment to health or the death of the organism.* That alcohol may do this is well known by scientists. The following quotations show that a large number of very eminent professors and physicians have this belief.

"The rather recent experiments of Atwater, which were made under special conditions to exclude everything but the one question of the heat and energy-producing action of alcohol in the human body, have been published and quoted over and over again as showing that it is in all respects a valuable food and not in any way deleterious to the system. The fact that these experiments had no reference to the action of the agent on the circulatory or nervous systems, which are by far its most important effects, is never mentioned. The single truth that alcohol is consumed in the body, producing heat and energy, proves no more that it is a useful food, as one of Professor Atwater's colleagues says, than would the fact that gunpowder burns up, producing heat and energy, prove it a profitable fuel for the stove." — *Journal of the American Medical Association*, Editorial, Nov. 25, 1899, page 1365.

"Life is not to be accounted for upon the theory of oxidation processes, but rather to be viewed under the aspect that with the vital processes is associated a constant consumption of energy and transformation of the same into other forms, — work and heat. This puts a new aspect upon the theory that alcohol is a fuel food. Only substances

which can enter the cell and become living matter can be food and have an animating effect. This alcohol cannot do.

"Hence the idea that alcohol economizes heat by its abundant heat production is a fallacy."—Dr. A. Holitscher, Pirkenhammer, *International Monatsschrift*, April, 1907.

"Obviously only such substances can be called food material, or be employed for food, as, like albumen, fat, and sugar, exert non-poisonous influence in the amounts in which they reach the blood and must circulate in it in order to nourish. . . . Although alcohol contributes energy, it diminishes working ability. We are not able to find that its energy is turned to account for nerve and muscle work. Very small amounts, whose food value is insignificant, show an injurious effect upon the nervous system."—Professor Grube, President of the Royal Institute of Hygiene, Munich, in the *Münchener Neuesten Nachrichten*, May 19, 1903.

"In view of the current tendency to regard alcohol as a food, it seemed desirable to make a study of its effects on hepatic glycogenesis, for if alcohol can replace the carbohydrates in food, it ought to spare the carbohydrate radical of the tissue proteids. An accumulation of glycogen in the liver after exclusive feeding with alcohol might therefore be expected. . . .

"This suggestion was put to an experimental test. The investigation was carried out entirely on rabbits which were fed exclusively on alcohol for periods of 4 to 6 days. Alcohol was given by mouth by means of a stomach tube in amounts varying between 3 to 9 cc. per kilo per rabbit, diluted to 30 and 60 per cent. As controls, rabbits were used that had been starved for the same number of days as the alcohol rabbits. Instead of alcohol, water was given by mouth with a stomach tube. At the expiration of the periods named, the rabbits were killed under ether anesthesia and the liver examined for glycogen according to Pflüger's shorter method. . . . The results at this stage of the investigation showed that in rabbits fed exclusively on alcohol (10 cc. 30% per kilo, or 12 cc. 60% per kilo) daily for four or five days, there is no accumulation of glycogen in the liver, which shows that glycogen is not formed in the liver of rabbits when fed on alcohol alone."—William Salant, *American Medicine*, April, 1906, page 41.

"**Alcohol is not a Food.**—It is said to be a food because eminent chemists tell us it can be oxidized, but it has been pointed out that some of the substances that are most readily oxidized are the most virulent poisons. Alcohol is a poison; it acts as a poison; it is oxidized as a poison. It contains certain elements of food necessary for the production of heat, but they are arranged in such a form that they cannot be properly utilized by our bodies as at present constituted. It is not a food because it contains certain elements that are necessary for the building up of our bodies. It is only when these are in proper form that they do

not in any way act as poisonous susbstances." — Professor G. Sims Woodhead, M.A., M.D., F.R.S.E., Professor of Pathology, Cambridge University, England.

" From an exhaustive definition we shall have to class every substance as a poison which, on becoming mixed with the blood, causes a disturbance in the function of any organ. That alcohol is such a poison cannot be doubted. . . . . Very appropriately has the English language named the disturbance caused by alcoholic beverages *intoxication*, which, by derivation, means poisoning." — Dr. Adolph Fick, Professor of Physiology, Würzburg, Germany.

" We know that alcohol is mostly oxidized in our body. . . . Alcohol is, therefore, without doubt, a source of living energy in our body, but it does not follow from this that it is also a nutriment. To justify this assumption, proof must be furnished that the living energy set free by its oxidation is utilized for the purpose of a normal function. It is not enough that potential energy is transformed into living energy; the transformation must take place at the right time and place, and at definite points in definite elements of the tissues. These elements are not adapted to be fed with every sort of oxidizable material. We do not know whether alcohol can furnish to the muscles and nerves a source of energy for the performance of their functions. . . . In general, alcohol has only paralyzing properties, etc." — G. Bunge, *Lehrbuch der Physiologischen und Pathologischen Chemie.*

" Alcohol, also, when not taken in too large quantities, may be oxidized in the body, and furnish a not inconsiderable amount of energy. It is, however, a matter of controversy at present, whether alcohol in small doses can be considered a true foodstuff capable of serving as a direct source of energy, and of replacing a corresponding amount of fats and carbohydrates in the daily diet." — William H. Howell, *American Textbook of Physiology.*

" The nutritive value of alcohol has been the subject of considerable discussion and not a few experiments. Some of these tend to show that in moderate non-poisonous doses it acts as a non-proteid food in diminishing the oxidation of proteid, doubtless by becoming itself oxidized. Its action, however, in this respect, is relatively small, and, indeed, a certain proportion of the alcohol ingested is exhaled with the air of respiration.

" Moreover, in large doses it (alcohol) may act in a contrary manner, increasing the waste of tissue proteid. It cannot, in fact, be doubted that any small production of energy resulting from its oxidation is more than counterbalanced by its deleterious influence as a drug upon the tissue elements, and especially upon those of the nervous system." — E. A. Schaefer, *A Textbook of Physiology.*

Dr. Kellogg points out that strychnine, quinine, and many other drugs are oxidized in the body, but surely cannot be called foods.

The following reasons for not considering alcohol a food are taken from his writings: —

"1. A habitual user of alcohol has an intense craving for his accustomed dram. Without it he is entirely unfitted for business. One never experiences such an insane craving for bread, potatoes, or any other particular article of food.

"2. By continuous use the body acquires a tolerance for alcohol. That is, the amount which may be imbibed and the amount required to produce the characteristic effects first experienced gradually increase until very great quantities are sometimes required to satisfy the craving which its habitual use often produces. This is never the case with true foods. . . . Alcohol behaves in this regard just as does opium or any other drug. It has no resemblance to a food.

"3. When alcohol is withdrawn from a person who has been accustomed to its daily use, most distressing effects are experienced. . . . Who ever saw a man's hand trembling or his nervous system unstrung because he could not get a potato or a piece of cornbread for breakfast? In this respect, also, alcohol behaves like opium, cocaine, or any other enslaving drug.

"4. Alcohol lessens the appreciation and the value of brain and nerve activity, while food reënforces nervous and mental energy.

"5. Alcohol as a protoplasmic poison lessens muscular power, whereas food increases energy and endurance.

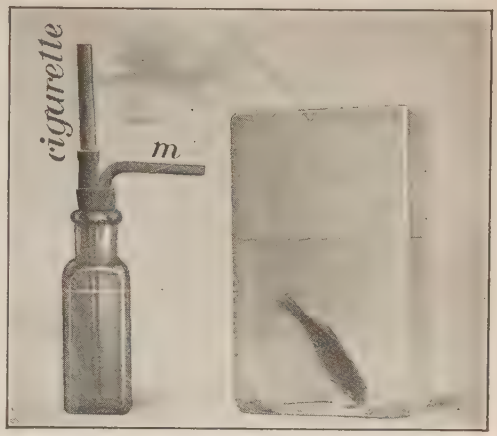
"6. Alcohol lessens the power to endure cold. This is true to such a marked degree that its use by persons accompanying Arctic expeditions is absolutely prohibited. Food, on the other hand, increases ability to endure cold. The temperature after taking food is raised. After taking alcohol, the temperature, as shown by the thermometer, is lowered.

"7. Alcohol cannot be stored in the body for future use, whereas all food substances can be so stored.

"8. Food burns slowly in the body, as it is required to satisfy the body's needs. Alcohol is readily oxidized and eliminated, the same as any other oxidizable drug."

The Use of Tobacco. — A well-known authority defines a narcotic as a substance "*which directly induces sleep, blunts the senses and, in large amounts, produces complete insensibility.*" Tobacco, opium, chloral, and cocaine are examples of narcotics. Tobacco owes its narcotic influence to a strong poison known as nicotine. Its use in killing insect parasites on plants is well known. In experiments with jellyfish and other lowly organized animals, the author has found as small a per cent as one part of nicotine to one hundred thousand parts of sea water to be sufficient to profoundly

affect an animal placed within it. The illustration here given shows its effect upon a fish, one of the vertebrate animals. Nicotine in a pure form is so powerful a poison that two or three drops would be sufficient to cause the death of a man by its action upon the nervous system, especially the nerves controlling the beating of the heart. This action is well known among boys training for athletic contest. The heart is affected; boys become "short-winded" as a result of the action on the heart. It has been demonstrated that tobacco has, too, an important effect on muscular development. The stunted appearance of the young smoker is well known.

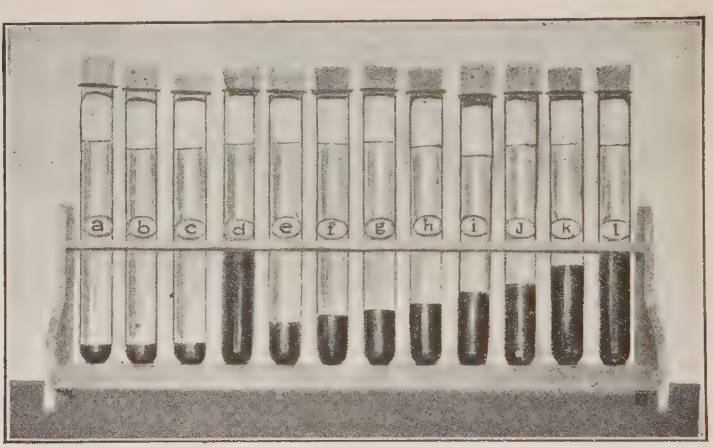


Experiment (by Davison) to show how tobacco affects the nervous system. The nicotine, caught in the water by passing through it the smoke from six cigarettes, was sufficient to kill the fish in the jar.

Problem XLIV. *A study of some medical frauds.* (*Laboratory Manual, Prob. XLIV.*)

Use and Abuse of Drugs. — The American people are addicted to the use of drugs and, especially, patent medicines. A glance at the street car advertisements shows this. Most of the medicines advertised contain alcohol in greater quantity than beer or wine, and nearly all of them have opium, morphine, or cocaine in their composition. Dr. George D. Haggard of Minneapolis has shown by many analyses that a large number of the so-called "malts," "malt extracts," and "tonics," including several of the best known and most advertised on the market, are simply disguised beers and, frequently, very poor beers at that. These drugs, in addition to being harmful, affect the person using them in such a manner

that he soon feels the need for the drug. Thus the drug habit is formed, — a condition which has wrecked thousands of lives. A number of articles on patent medicines recently appeared in a



The amounts of alcohol in some liquors and in some patent medicines.

a, beer, 5 % ; *b*, claret, 8 % ; *c*, champagne, 9 % ; *d*, whisky, 50 % ; *e*, well-known sarsaparilla, 18 % ; *f*, *g*, *h*, much-advertised nerve tonics, 20 %, 21 %, 25 % ; *i*, another much-advertised sarsaparilla ; *j*, a well-known tonic, 28 % ; *k*, *l*, bitters, 37 %, 44 % alcohol.

leading magazine and have been collected and published under the title of " The Great American Fraud." Every boy and girl should read these so as to be forearmed against such evils.

Reference Reading on Foods

Sharpe, *A Laboratory Manual for the Solution of Problems in Biology.* American Book Company.
Davison, *The Human Body and Health.* American Book Company.
Bulletin 13, *American School of Home Economics*, Chicago.
The Great American Fraud. American Medical Association, Chicago.
Allen, *Civics and Health.* Ginn and Company.
Cornell University Reading Course, Buls. 6 and 7, *Human Nutrition.*
Lusk, *Science and Nutrition.* W. B. Saunders Company.
The Propaganda for Reform in Proprietary Medicines. American Medical Association.

Some Government Publications on Nutrition and Foods

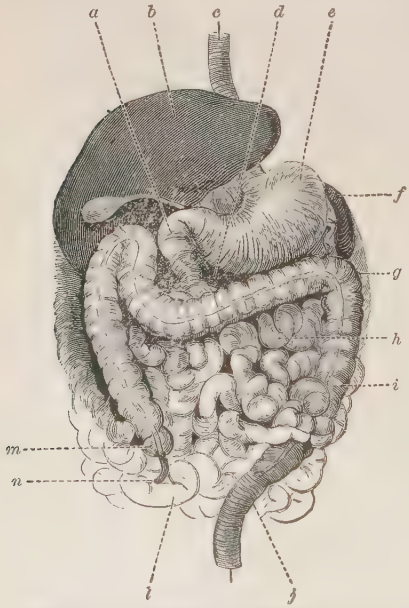
(To be obtained from the Secretary of Agriculture, Washington.)

No. Farmers' Bulletin :
23 Foods : Nutritive Value and Cost.

142 Principles of Nutrition and Nutritive Value of Food.
34 Meats: Composition and Cooking.
128 Eggs: Their Use as Food.
85 Fish as Food.
121 Legumes as Food.
132 Nuts and their Use as Food.
298 Corn and Corn Products.
42 Facts about Milk.
249 Cereal Breakfast Foods.
93 Sugar as Food.
182 Poultry as Food.
295 Potatoes and other Root Crops as Food.

Reprint from Yearbook, 1901, Atwater, *Dietaries in Public Institutions.*
Reprint from Yearbook, 1902, Milner, *Cost of Food related to its Nutritive Value.*
Experiment Station, Circular 46, Langworthy, *Functions and Uses of Food.*

Purpose of Digestion. — We have learned that starch and proteid food of plants are formed in the leaves. A plant, however, is unable to make use of the food in this condition. Before it can be transported from one part of the plant body to another, it is changed into a soluble form. In this state it can be passed from cell to cell by the process of osmosis. Much the same condition exists in animals. In order that food may be of use to man, it must be changed into a state that will allow of its passage in a soluble form through the walls of the alimentary canal, or food tube. *Digestion consists in the changing of foods from an insoluble to a soluble form, so that they may pass through the walls of the alimentary canal and become part of the blood.*



Picture of the organs of digestion: *a*, intestine, leading out of the pylorus; *b*, liver; *c*, esophagus; *d*, pancreas; *e*, stomach; *f*, spleen; *g*, *i*, *j*, *k*, *m*, *n*, parts of large intestine; *h*, *l*, small intestine. (From Johonnot and Bouton.)

Problem XLV. *Study of the digestive system of a frog in order better to understand that of man.* (*Laboratory Manual, Prob. XLV.*)

Alimentary Canal. — In all vertebrate animals, including man, food is normally taken in the mouth and passed through a food tube during the process of digestion. This tube is composed of different portions, named, respectively, as we pass from the mouth, posteriorly, the *gullet*, *stomach*, *small* and *large intestine*, and *rectum*.

Glands. — In addition to the alimentary canal proper, we find a number of *digestive glands*, varying in size and position, connected with the canal. As we have already learned, a gland is a collection of cells which takes up materials from within the body and pours out this material as a secretion. An example of glands in plants is found in the nectar glands of a flower.

Certain substances called *enzymes* formed by glands cause the digestion of food. The enzymes secreted by the cells of the glands and poured out into the food tube act upon insoluble foods so as to change them to a soluble form.

Structure. — The entire inner surface of the food tube is covered with a soft lining of *mucous membrane*. This is always moist because certain cells, called *mucus cells*, empty out their contents into the food tube, thus lubricating its inner surface. When a large number of cells which have the power to secrete fluids are collected together, the surface of the food tube may become indented at this point to form a pitlike *gland*. Often such depressions are branched, thus giving a greater secreting surface, as is seen in the Figure. The cells of the gland are always supplied with blood vessels and nerves, for the secretions of the glands are under the control of the nervous system. Think of a sour pickle and note what happens.

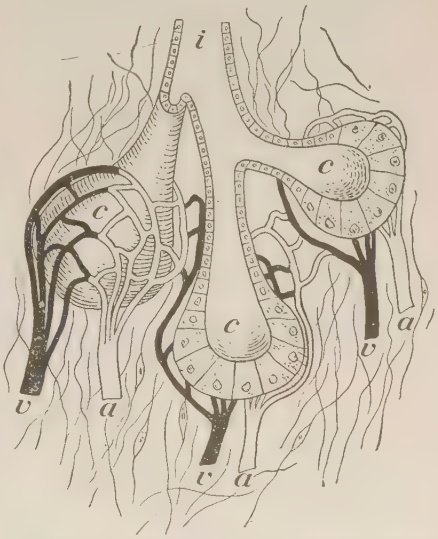


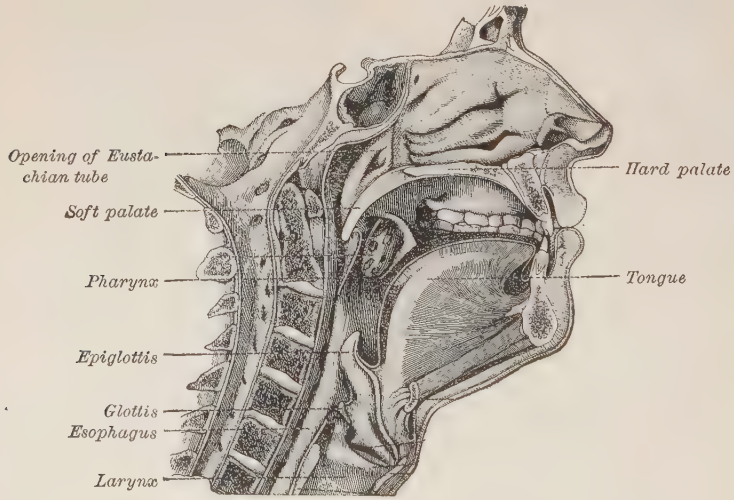
Diagram of a gland: *i*, the common tube which carries off the secretions formed in the cells lining the cavity *c*; *a*, arteries carrying blood to the glands; *v*, veins taking blood away from the gland.

Attached to the digestive tract of man are found, besides the salivary glands in the mouth, *gastric* glands in the walls of the stomach, the *liver* and the *pancreas*, two large glands which empty

into the small intestine just below the stomach, and certain glands (*intestinal glands*) in the wall of the intestine.

It will be the purpose of this chapter to follow the various food substances in the passage through the food tube in order to find *how* and *where* the changes take place in the various nutrients which prepare them to become part of the blood.

Mouth Cavity in Man. — In our study of a frog we found that the mouth cavity had two unpaired and four paired tubes leading from it. These are (*a*) the *gullet* or food tube, (*b*) the *windpipe* (in the frog opening through the *glottis*), (*c*) the paired nostril holes (*posterior nares*), (*d*) the paired *Eustachian tubes*, leading to the ear. All of these openings are found in man.



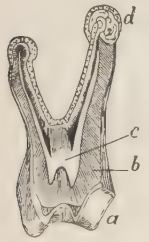
The mouth cavity of man.

In man the mouth cavity, and all internal surfaces of the food tube, are lined with a *mucous membrane*. The *mucus* secreted from gland cells in this lining makes a slippery surface so that the food may slip down easily. The roof of the mouth is formed in front by a plate of bone called the *hard palate*, and a softer continuation to the back of the mouth, the *soft palate*. These separate the nose cavity from that of the mouth proper. The part

of the space back of the soft palate is called the *pharynx*, or throat cavity. From the pharynx lead off the *gullet* and *windpipe*, the latter placed ventral to the former. The lower part of the buccal cavity is occupied by a muscular tongue. Examination of its surface with a looking-glass shows it to be almost covered in places by tiny projections called *papillæ*. These papillæ contain organs known as *taste buds*, the sensory endings of which determine the taste of substances. The tongue is also used in moving food about in the mouth, and in starting it on its way to the gullet, while it plays an important part, as we know, in speaking.

Teeth *i*, incisors; *c*, canine; *p*, premolars; *m*, molars.

The Teeth. — In man the teeth, unlike those of the frog, are used for the mechanical preparation of the food for digestion. Instead of holding prey, they crush, grind, or tear food so that more surface may be given for the action of the digestive fluids. The teeth of man are divided, according to their functions, into four groups. In the center of both the upper and lower jaw in front are found eight teeth with chisel-like edges, four in each jaw; these are the *incisors*, or cutting teeth. Next is found a single tooth on each side (four in all); these have rather sharp points; they are the *canines;* look for them in a cat or dog. Then come two teeth on each side, eight in all, called *premolars*. Lastly, the *flat-top molars*, or grinding teeth, of which there are six in each jaw. Food is caught between irregular projections on the surface of the molars and crushed to a pulpy mass.



Section of a tooth: *a*, enamel; *b*, dentine; *c*, pulp cavity containing blood vessels and nerves; *d*, cement.

Internal Structure of a Tooth. — If a tooth is cut lengthwise, it is found to be hollow; this

cavity, called the *pulp cavity*, corresponds to the cavity containing marrow in bones. In life it contains living material — the blood vessels, nerves, and cells which build up the bony part of the tooth. The bulk of the hard part of the tooth consists of a limy material called *dentine*. Outside of this is a very hard substance called *enamel;* this substance, the hardest in all the body, is thickest on the exposed surface or crown of the tooth. Each tooth is held in its place in the jawbone by a thin layer of bony substance called *cement*.

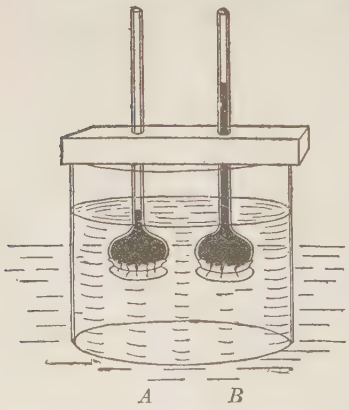
Problem XLVI. *How foods are chemically prepared for absorption into the blood.* (*Laboratory Manual, Prob. XLVI.*)

(*a*) *In the mouth.*

(*b*) *In the stomach.*

(*c*) *In the small intestine.*

Salivary Glands. — We are all familiar with the substance called *saliva* which acts as a lubricant in the mouth. Saliva is manufactured in the cells of three pairs of glands which empty into the mouth, and which are called, according to their position, the *parotid* (under the ear), the *submaxillary* (under the jawbone), and the *sublingual* (under the tongue).



Experiment showing non-osmosis of starch in tube *A*, and osmosis of sugar in tube *B*.

Digestion of Starch. — If we collect some saliva in a test tube, add to it a little starch paste, place the tube containing the mixture for a few minutes in tepid water, and then test with Fehling's solution, we shall find grape sugar present. Careful tests of the starch paste and of the saliva made separately will usually show no grape sugar in either.

If another test be made for grape sugar, in a test tube containing starch paste, saliva, and a few drops of any weak acid, the starch will be found not to have changed. The digestion of starch to grape sugar is caused by the presence in the saliva of an *enzyme*, or *digestive ferment*. You will remember that starch in the growing corn grain was changed to grape sugar

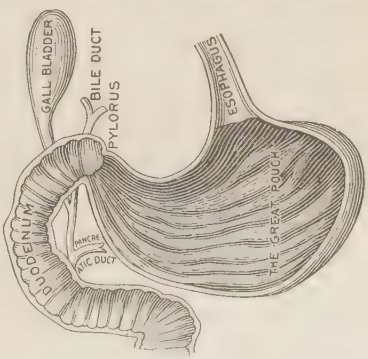
by an enzyme called diastase. Here the same action is caused by an enzyme called *ptyalin*. This ferment, as we can prove, acts *only* in an alkaline medium at about the temperature of the body.

How Food is Swallowed. — After food has been chewed and mixed with saliva, it is rolled into little balls and pushed by the tongue into such position that the muscles of the throat cavity may seize it and force it downward. Food, in order to reach the gullet from the mouth cavity, must pass over the *glottis*, the opening into the windpipe, or *trachea*. When food is in the course of being swallowed, the upper part of this tube forms a trapdoor over the opening. When this trapdoor is not closed, and food "goes down the wrong way," we choke, and the food is expelled by coughing.

The Gullet, or Esophagus. — In man this part of the food tube is much longer proportionately than in the frog. Like the rest of the food tube it is lined by soft and moist mucous membrane. The wall is made up of two sets of muscles, — the inside ones running around the tube; the outer band of muscle taking a longitudinal course. After food leaves the mouth cavity, it gets beyond our direct control, and the muscles of the gullet, stimulated to activity by the presence of food in the tube, push the food down to the stomach by a series of contractions until it reaches the stomach. The gullet passes directly through a muscular partition, the *diaphragm*, which is lacking in the frog. The diaphragm separates the heart and lungs from the other organs of the body cavity.

Stomach of Man.—The stomach is a pear-shaped organ capable of holding about three pints. The end opposite to the gullet, which empties into the small intestine, is provided with a ring of muscle forming a valve called the *pylorus*.

Gastric Glands.—If we open the stomach of the frog, and remove its contents by carefully washing, its wall is seen to be thrown into folds internally. Between the folds



Inside of the stomach and intestine, showing the folds of the mucous membrane.

in the stomach of man, as well as in the frog, are located a number of tiny pits. These form the mouths of the *gastric glands*, which pour into the stomach a secretion known as the *gastric juice*. The gastric glands are little tubes, the lining of which secretes the fluid. This fluid is largely water. It is slightly acid in its chemical reaction, containing about .2 per cent *free hydrochloric acid*. It also contains a very important enzyme called *pepsin*, and another less important one called *rennin*.

A peptic gland, from the stomach, very much magnified. *A*, central or chief cells, which make pepsin; *B*, border cells, which make acid. (From Miller's *Histology*.)

Action of Gastric Juice. — If proteid is treated with artificial gastric juice at the temperature of the body, it will be found to become swollen and then gradually to change to a substance which is soluble in water.

Most proteid substances are insoluble. They belong to the class of substances known as *colloids* — substances that do not easily pass through a membrane by osmosis. After proteid is digested in the stomach, it is known as a *peptone*. Digestion of proteid results in a change of a colloid substance to one which will diffuse readily through a membrane, or a *crystalloid*. Peptones are crystalloid substances.

The other enzyme of gastric juice, called *rennin*, curdles or coagulates a proteid found in milk; after the milk is curdled, the pepsin is able to act upon it. "Junket" tablets, which contain rennin, are used in the kitchen to cause this change.

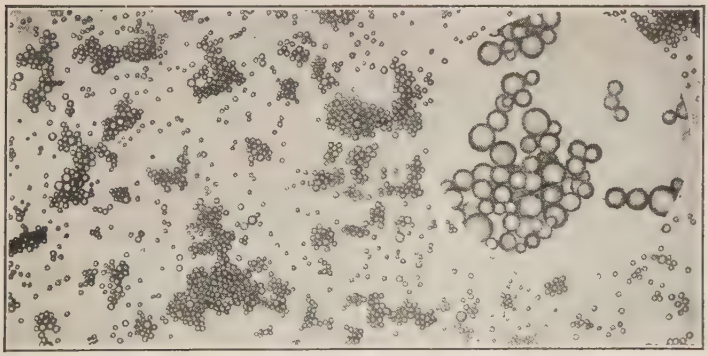
The hydrochloric acid found in the gastric juice acts upon lime and some other salts taken into the stomach with food, changing them so that they may pass into the blood and eventually form the mineral part of bone or other tissue.

Movement of Walls of Stomach. — The stomach walls, provided with three layers of muscle which run in an oblique, circular, and longitudinal direction (taken from the inside outward), are well fitted for the constant churning of the food in that organ. Here, as elsewhere in the digestive tract, the muscles are involuntary, muscular action being under the control of the so-called *sympathetic nervous system*. Food material in the stomach makes several complete circuits during the process of digestion

in that organ. Contrary to common belief, the greatest amount of food is digested *after* it leaves the stomach. But this organ keeps the food in it in almost constant motion for a considerable time, a meal of meat and vegetables remaining in the stomach for three or four hours. While movement is taking place, the gastric juice acts upon proteids, softening them, while the constant churning movement tends to separate the bits of food into finer particles. Ultimately the semifluid food, most of it still undigested, is allowed to pass in small amounts through the pyloric valve, into the small intestines. This is done by the expansion of the ringlike muscles of the pylorus.

The partly digested food in the small intestine almost immediately comes in contact with fluids from two glands, the liver and pancreas. We shall first consider the function of the pancreas.

Position and Structure of the Pancreas. — The most important digestive gland in the human body is the pancreas. The gland is a rather diffuse structure; its duct empties in a common opening with the bile duct, a short distance below the pylorus. In internal structure, the pancreas resembles the salivary glands.



Appearance of milk under the microscope, showing the natural grouping of the fat globules. In the circle a single group is highly magnified. Milk is one form of an emulsion. (S. M. Babcock, Wis. Bul. No. 61.)

Starch added to artificial pancreatic fluid and kept at blood heat is soon changed to sugar. Proteid, under the same conditions, is changed to peptone. Fats, which so far have been unchanged except to be melted by the heat of the body, are changed by the action of the pancreas into a form which can pass through the walls of the food tube. If we test pancreatic fluid, we find it strongly

alkaline in its reaction. If two test tubes, one containing olive oil and water, the other olive oil and a weak solution of caustic soda, an *alkali*, be shaken violently and then allowed to stand, the oil and water will quickly separate, while the oil, caustic soda, and water will remain for some time in a milky *emulsion*. If this emulsion be examined under the microscope, it will be found to be made of millions of little droplets of fat, floating in the liquid. The presence of the caustic soda helped the forming of the emulsion. Pancreatic fluid similarly emulsifies fats and changes them into soft soaps and fatty acids. Fat in this form may be absorbed. The process of this transformation is not well understood.

Liver. — The liver is the largest gland in the body. In man, it hangs just below the diaphragm, a little to the right side of the body. During life, its color is deep red. It is divided into three lobes, between two of which is found the *gall bladder*, a thin-walled sac which holds the *bile*, a secretion of the liver. Bile is a strongly alkaline fluid of greenish color. It reaches the intestine through a common opening with the pancreatic fluid. Almost one quart of bile is passed daily into the digestive canal.

Functions of Bile. — The action of bile on foods is not very well known. It is slightly antiseptic, and thus may prevent fermentation within the intestine by destroying bacteria. It also has the very important faculty of aiding the passage of fats through the walls of the intestine. If two funnels, each containing filter paper, one moistened with bile, the other dry, be filled with oil, the oil will be found to pass through the moistened funnel with much greater ease.

Formation of Glycogen. — Perhaps the most important function of the liver is the formation within it of a material called *glycogen*, or animal starch. The liver is supplied by blood from two sources. The greater amount of blood received by the liver comes directly from the walls of the stomach and intestine to this organ. It normally contains about one fifth of all the blood in the body. This blood is very rich in food materials, and from it the cells of the liver take out sugars to form glycogen.[1] Glycogen is stored in the liver. When food which can be oxidized quickly is needed, the glycogen is changed to sugar and carried off by the blood to the tissues

[1] It is known that glycogen *may* be formed in the body from proteid, and possibly from fatty foods.

which require it, and there used for this purpose. Glycogen is also stored in the muscles, where it is oxidized to release energy when the muscles are exercised.

Problem XLVII. *A study of where and how digested foods pass into the blood.* (*Laboratory Manual, Prob. XLVII.*)

The Absorption of Digested Food into the Blood. — The object of digestion is to change foods from an insoluble to a soluble form. This has been seen in the study of the action of the various digestive fluids in the body, each of which is seen to aid in dissolving solid foods, changing them to a fluid, and, in case of the bile, actually assisting them to pass through the wall of the intestine. A small amount of digested food may be absorbed by the blood in the blood vessels of the walls of the stomach. Most of the absorption, however, takes place through the walls of the small intestine.

Structure of the Small Intestine. — The small intestine in man is a slender tube nearly twenty feet in length and about one inch in diameter. Its walls contain muscles which, by a series of slow waves of contraction, force the fluid food gradually toward the posterior end of the tube. The movements of the muscles of the coat are of very great importance in the process of absorption, and these movements are caused to a great extent (as is the secretion of the various glands of the food tube) by the mechanical stimulus of the food within the food tube. If the chief function of the small intestine is that of absorption, we must look for adaptations which increase the absorbing surface of the tube. This is gained in part by the

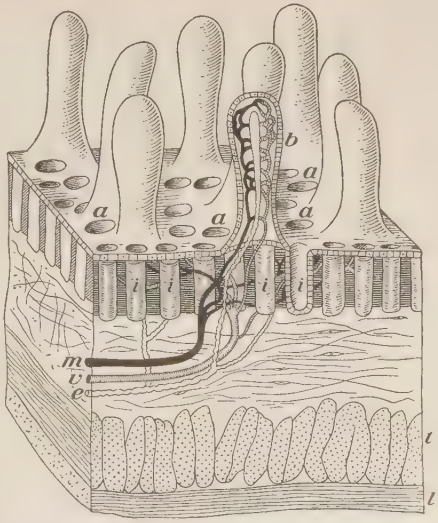


Diagram of a bit of the wall of the small intestine, greatly magnified. *a*, mouths of intestinal glands; *b*, villus cut lengthwise to show blood vessels and lacteal (in center); *c*, lacteal sending branches to other villi; *i*, intestinal glands; *m*, artery; *v*, vein; *l*, *t*, muscular coats of intestine wall.

inner surface of the tube being thrown into transverse folds which not only retard the rapidity with which food passes down the intestine, but also give more absorbing surface. But far more important for absorption are millions of little projections which cover the inner surface of the small intestine.

The Villi. — So numerous are these projections that the whole surface presents a velvety appearance. Collectively, these structures are called the *villi* (singular *villus*). They form the chief organs of absorption in the intestine, several thousand being distributed over every square inch of surface. By means of the folds and villi the small intestine is estimated to have an absorbing surface equal to twice that of the surface of the body. Between the villi are found the openings of many small tubelike glands, the *intestinal glands*. These glands manufacture a digestive fluid, strongly alkaline, which aids in digesting fats, and acts somewhat like the pancreatic fluid.

Internal Structure of a Villus. — The internal structure of a villus is best seen in a longitudinal section. We find the outer wall made up of a thin layer of cells, the *epithelial* layer. It is the duty of these cells to absorb the semifluid food from within the intestine. Underneath these cells lies a network of very tiny blood vessels, while inside of these, occupying the core of the villus, are found spaces which, because of their white appearance after absorption of fats, have been called *lacteals*.

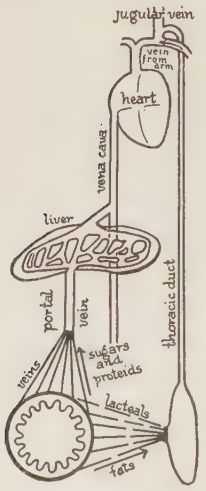


Diagram showing how food reaches the circulation.

Absorption of Foods. — Let us now attempt to find out exactly how foods are passed from the intestines into the blood. Food substances in solution may be soaked up as a sponge would take up water, or they may pass by osmosis into the cells lining the villus. These cells are alive, and therefore have the power of selecting certain substances and rejecting others. Once within the villus, the sugars and digested proteids pass through tiny blood vessels into the larger vessels comprising the *portal circulation*. These pass through the liver, where

as we have seen, sugar is taken from the blood and stored as glycogen. From the liver, the food within the blood is sent to the heart, from there is pumped to the lungs, from there returns to the heart, and is pumped to the tissues of the body. A large amount of water and some salts are also absorbed through the walls of the stomach and intestine as the food passes on its course. The fats in the form of soaps and fatty acids pass into the space in the center of the villus. Later they are changed into fats again, probably in certain groups of gland cells known as *mesenteric* glands, and eventually reach the blood by way of the thoracic duct *without* passing through the liver.

Large Intestine. — The large intestine has somewhat the same structure as the small intestine, except that the diameter is much greater. It also contains no villi. Considerable absorption, however, takes place through its walls as the mass of food and refuse material is slowly pushed along by the muscles within its walls.

In this portion of the intestine live millions of bacteria, some of which manufacture poisonous substances from the foods on which they live. These substances are easily absorbed through the walls of the large intestine, and passing into the blood, cause headaches or sometimes serious trouble. Hence it follows that the lower bowel should be emptied of this matter as frequently as possible, at least once a day. Constipation is one of the most serious evils the American people have to deal with, and it is largely brought about by the artificial life which we lead, with its lack of exercise, fresh air, and sleep.

Vermiform Appendix. — At the point where the small intestine widens to form the large intestine, a baglike pouch is formed. From one side of this pouch is given off a small tube about four inches long, closed at the lower end. This tube, the function of which in man is unknown, is called the *vermiform appendix*. It has come to have unpleasant notoriety in late years, as the site of serious inflammation. It often becomes necessary to remove the appendix in order to prevent this inflammation from spreading to the surrounding tissues.

Hygienic Habits of Eating; the Causes and Prevention of Dyspepsia. — From the contents of the foregoing chapter it is evident that the object of the process of digestion is to break up solid food so that it may be absorbed to form part of the blood. Any habits we may form of thoroughly chewing our food will evidently aid in this process. Undoubtedly much of the distress known as dyspepsia is due to too hasty meals with consequent lack of proper

mastication of food. The message of Mr. Fletcher in bringing before us the need of proper mastication of food and the attendant evils of overeating is one which we cannot afford to ignore. It is a good rule to go away from the table feeling hungry. Eating too much overtaxes the digestive organs and prevents their working to the best advantage. Still another cause of dyspepsia is eating when in a fatigued condition. It is always a good plan to rest a short time before eating, especially after any hard manual work. Eating between meals is also condemned by physicians because it calls the blood to the digestive organs at a time when it should be in other parts of the body.

Effect of Alcohol on Digestion. — It is a well-known fact that alcohol extracts water from tissues with which it is in contact. This fact works much harm to the interior surface of the food tube, especially the walls of the stomach, which in the case of a hard drinker are likely to become irritated and much toughened. In small amounts alcohol stimulates the secretion of the salivary and gastric glands, and thus seems to aid in digestion. It is doubtful, however, whether this aid is real.

The following results of experiments on dogs, published in the *American Journal of Physiology,* Vol. I, Professor Chittenden of Yale University gives as "strictly comparable," because "they were carried out in succession on the same day." They show that alcohol retards rather than aids in digestion: —

Number of Experiment	$\frac{1}{10}$ Lb. Meat with Water	$\frac{1}{10}$ Lb. Meat with Dilute Alcohol
XVII α 9 : 15 A.M.	Digested in 3 hours	
XVII β 3 : 00 P.M.		Digested in 3 : 15 hours
XVIII α 8 : 30 A.M.	Digested in 2 : 30 hours	
XVIII β 2 : 10 P.M.		Digested in 3 : 00 hours
XIX α 9 : 00 A.M.	Digested in 2 : 30 hours	
XIX β 2 : 30 P.M.		Digested in 3 : 00 hours
XX α 9 : 15 A.M.		Digested in 2 : 45 hours
XX β 2 : 30 P.M.	Digested in 2 : 15 hours	
VI α 9 : 15 A.M.		Digested in 3 : 45 hours
VI β 1 : 00 P.M.	Digested in 3 : 15 hours	
Average	2 : 42 hours	3 : 09 hours

As a result of his experiments, Professor Chittenden remarks: "We believe that the results obtained justify the conclusion that gastric digestion as a whole is not materially modified by the introduction of alcoholic fluids with the food. In other words, the unquestionable acceleration of gastric secretion which follows the ingestion of alcoholic beverages is, as a rule, counterbalanced by the inhibitory effect of the alcoholic fluids upon the chemical process of gastric digestion, with perhaps at times a tendency towards preponderance of inhibitory action." Dr. Kellogg, Sir William Roberts, and others have come to the same or stronger conclusions as to the undesirable action of alcohol on digestion, as a result of their own experiments.

Horsley and Sturge say: "Hundreds of men and women who haunt the out-patient departments of hospitals suffer from chronic atony and slight dilatation of the stomach, which arise in part from the badly cooked food they eat, but chiefly owe their origin to the debilitating effect of alcohol upon the muscular walls of this organ and the fermentation of its retained contents."

XXVI. THE BLOOD AND ITS CIRCULATION

Problem XLVIII. *To study the composition of the blood.* (*Laboratory Manual, Prob. XLVIII.*)

Function of the Blood. — The chief function of the digestive tract is to change foods to such form that they can be absorbed through the walls of the food tube and become part of the blood.[1] By means of a system of closed tubes, this fluid tissue circulates to all parts of the body, equalizing the body temperature by depositing its burden of food in places where it is most needed and where it will be used, either in the repair and building of tissues or for oxidation within the cells of the body to release energy.

If we examine under the microscope a drop of blood taken from the frog or man, we find it made up of a fluid called *plasma* and two kinds of bodies, the so-called *red corpuscles* and *colorless corpuscles*, floating in this plasma.

Composition of Plasma. — The plasma of blood (when chemically examined in man) is found to be largely (about 90 per cent) water. It also contains a considerable amount of proteid, some sugar, fat, and mineral material. It is, then, the medium which holds the fluid food (or at least part of it) that has been absorbed from within the intestine. The almost constant temperature of the body is also due, as we shall see, to the blood which brings to the surface of the body much of the heat given off by oxidation of food in the muscles and glands within. When the blood returns from the tissues where the food is oxidized, the plasma brings back with it to the lungs the carbon dioxide liberated from the tissues of the body where oxidation has taken place. Blood returning from the tissues of the body has from 45 to 50 c.c. of carbon dioxide

[1] This change is due to the action of certain enzymes upon the nutrients in various foods. But we also find that peptones are changed back again to proteids when once in the blood. This appears to be due to the *reversible* action of the enzymes acting upon them. (See page 72.)

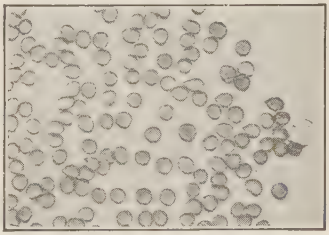
to every 100 c.c. (See Chapter XXVII.) Some waste products, to be spoken of later, are also found in the plasma.

Clotting of Blood. — If fresh beef blood is allowed to stand overnight, it will be found to have separated into two parts, a dark red, almost solid *clot* and a thin, straw-colored liquid called *serum*. Serum is found to be made up of about 90 per cent water, 8 to 9 per cent proteid, and from 1 to 2 per cent sugars, fats, and mineral matter. In these respects it very closely resembles the fluid food that is absorbed from the intestines.

If another jar of fresh beef blood is poured into a pan and briskly whipped with a bundle of little rods (or with an egg beater), a stringy substance will be found to stick to the rods. This, if washed carefully, is seen to be almost colorless. Tested with nitric acid and ammonia, it is found to contain a proteid substance called *fibrin*.

Blood plasma, then, is made up of serum, a fluid portion, and fibrin, which, although in a fluid state in the blood vessels within the body, coagulates when blood is removed from the blood vessels. It is this coagulation which aids in the formation of a blood clot. A clot is simply a mass of fibrin threads with a large number of corpuscles tangled within. The clotting of blood is of great physiological importance, for otherwise we might bleed to death from the smallest wound.

In blood within the circulatory system of the body, the fibrin is held in a fluid state called *fibrinogen*. An enzyme, acting upon this fibrinogen, the soluble proteid in the blood, causes it to change to an insoluble form, the fibrin of the clot.



Human blood as seen under the high power of the compound microscope; at the extreme right is a colorless corpuscle.

The Red Blood Corpuscle; its Structure and Functions. — The red corpuscle in the blood of the frog is a true cell of disklike form. The red corpuscle of man, however, lacks a nucleus. Its form is that of a biconcave disk. So small and so numerous are these corpuscles that over five million are found in a drop of normal blood. The color, which is found to be a dirty yellow when separate corpuscles are viewed under the microscope, is due to a proteid

material called *hæmoglobin*. Hæmoglobin contains a large amount of iron. It has the power of uniting very readily with oxygen whenever that gas is abundant, and, after having absorbed it, of giving it up to the surrounding media, when oxygen is there present in smaller amounts than in the corpuscle. This function of carrying oxygen is the one most important function of the red corpuscle, although the red corpuscle also removes part of the carbon dioxide from the tissues on their return to the lungs. The taking up of oxygen is accompanied by a change in color of the mass of corpuscles from a dull red to a bright scarlet.

The Colorless Corpuscle; Structure and Functions. — A colorless corpuscle is a cell irregular in outline, the shape of which is constantly changing. These corpuscles are somewhat larger than the red corpuscles, but less numerous, there being about one colorless corpuscle to every three hundred red ones. They have the power of movement,

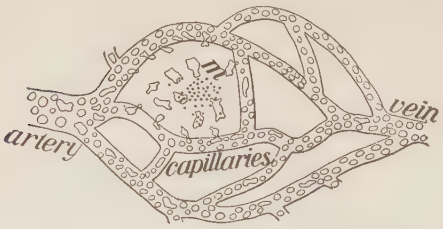
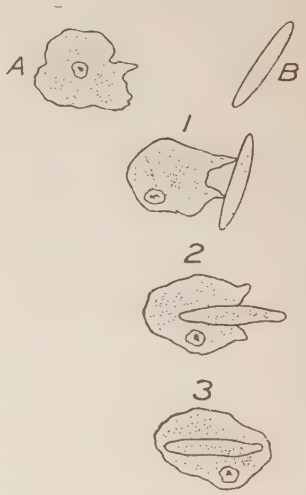


Diagram showing how the colorless corpuscles pass through the walls of the capillaries (smallest blood tubes) and ingulf the bacteria at *m*.



A colorless corpuscle catching and eating a germ.

for they are found not only inside blood vessels, but outside the blood tubes, showing that they have worked their way between the cells that form the walls of the blood vessels.

A Russian zoölogist, Metschnikoff, after studying a number of simple animals, such as medusæ and sponges, found that in such animals some of the cells lining the inside of the food cavity take up or ingulf minute bits of food. Later, this food is changed into the protoplasm of the cell. Metschnikoff believed that the colorless

corpuscles of the blood have somewhat the same function. This he later proved to be true. Like the amœba, they feed by ingulfing their prey. This fact has a very important bearing on the relation of colorless corpuscles to certain diseases caused by bacteria within the body. If, for example, a cut becomes infected by bacteria, inflammation may set in. Colorless corpuscles at once surround the spot and attack the bacteria. If the bacteria are few in number, they are quickly eaten by certain of the colorless corpuscles, which are known as *phagocytes*. If bacteria are present in great quantities, they may prevail and kill the phagocytes by poisoning them. The dead bodies of the phagocytes thus killed are found in the pus, or matter, which accumulates in infected wounds. In such an event, we must come to the aid of nature by washing the wound with some antiseptic, as weak carbolic acid or hydrogen peroxide.

The Amount of Blood and its Distribution. — The protoplasm of the body, as we know, is composed largely of water. Blood forms, by weight, about one thirteenth of the body. Its distribution varies somewhat according to the position assumed by the body, and the amount of undigested food in the stomach and intestines. Normally, about one half of the blood of the body is found in or near the organs lying in the body cavity, about one fourth in the muscles, and the rest in the heart, lungs, large arteries, and veins.

Blood Temperature. — The temperature of blood in the human body is normally about 98.5° Fahrenheit, although the temperature drops almost two degrees after we have gone to sleep at night. It is highest about 5 P.M. and lowest about 4 A.M. In fevers, the temperature of the body sometimes rises to 107° or higher; but unless this temperature is soon reduced, death follows. Any considerable drop in temperature below the normal also would mean death. Body heat, as we know, results from the oxidation of food; the constant circulation of blood keeping the temperature nearly uniform in all parts of the body. The body temperature may be from two to three degrees higher immediately after violent exercise. Why?

Cold-blooded Animals. — In animals which are called cold-blooded, the blood has no fixed temperature, but varies with the temperature of the medium in which the animal lives. Frogs, in the summer, may sit for hours in water with a temperature of almost 100°. In winter, they often endure freezing so that the blood and lymph within the spaces under the loose skin are frozen into ice crystals. Such frogs, if thawed out carefully, will live. This change in body temperature is evidently an adaptation to the mode of life.

Circulation of the Blood in Man. — The blood is the carrying agent of the body. Like a railroad or express company, it takes materials from one part of the human organism to another. This it does by means of the organs of circulation — the heart and blood vessels. These blood vessels are called *arteries* where they carry blood away from the heart, *veins* where they bring blood back to the heart, and *capillaries* where they connect the arteries with the veins. The organs of circulation thus form a system of connected tubes through which the blood flows in a continuous stream.

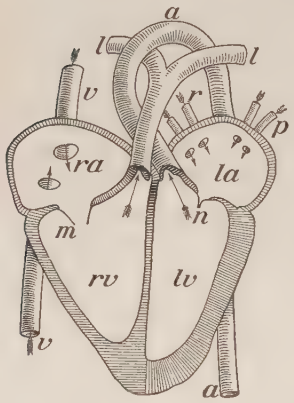
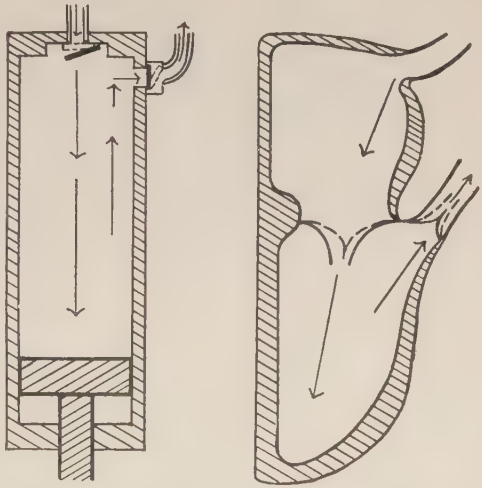


Diagram showing the front half of the heart cut away: *a*, aorta; *l*, arteries to the lungs; *la*, left auricle; *lv*, left ventricle; *m*, tricuspid valve open; *n*, bicuspid or mitral valve closed; *p* and *r*, veins from the lungs; *ra*, right auricle; *rv*, right ventricle; *v*, vena cava. Arrows show direction of circulation.

The Heart; Position, Size, Protection. — The heart is a cone-shaped muscular organ about the size of a man's fist. It is located immediately above the diaphragm, and lies so that the muscular apex, which points downward, moves while beating against the fifth and sixth ribs, just a little to the left of the midline of the body. This fact gives rise to the notion that the heart is on the left side of the body. The heart is surrounded by a loose membranous bag called the *pericardium*, the inner lining of which secretes a fluid in which the heart lies. When, for any reason, the pericardial fluid is not secreted, inflammation arises in that region. Do you know why?

Internal Structure of Heart. — If we should cut open the heart of a mammal down the midline, we could divide it into a right and a left side, each of which would have no internal connection with the other. Each side is made up of a thin-walled portion with a rather large internal cavity, the *auricle*, which opens into a smaller portion with heavy muscular walls, the *ventricle*. The auricles occupy the base of the cone-shaped heart; the ventricles, the apex. Communication between auricles and ventricles is guarded by little flaps

of muscle called *valves*. The auricles receive blood from the veins. The ventricles pump the blood into the arteries. From each ventricle, large arteries leave the heart; that of the left side is called the *aorta*. Through the aorta, blood passes to all parts of the body. From the right ventricle the *pulmonary artery* carries blood to the lungs. The openings to these arteries are guarded by three half-moon-shaped flaps, which open so as to allow blood to pass away from the ventricle, but not to go back into it when the muscles relax.



The heart is a force pump; prove it from these diagrams.

The Heart in Action. — The heart is constructed on the same plan as a force pump, the valves preventing the reflux of blood into the auricle after it is forced out of the ventricle. Blood enters the auricles from the veins because the muscles of that part of the heart relax; this allows the space within the auricles to fill. Almost immediately the muscles of the ventricles relax, thus allowing blood to pass into the chambers within the ventricles. Then, after a short pause, during which time the muscles of the heart are resting, a wave of muscular contraction begins in the auricles and ends in the ventricles, with a sudden strong contraction which forces the blood out into the arteries. Blood is kept on its course by the valves, which act in the same manner as do the valves in a pump, thus forcing the blood to pass into the arteries upon the contraction of ventricle walls.

The Course of the Blood in the Body. — Although the two sides of the heart are separate and distinct from each other, yet every drop of blood that passes through the left heart likewise passes through the right heart. There are two distinct systems of cir-

culation in the body. The *pulmonary circulation* takes the blood through the right auricle and ventricle, to the lungs, and passes it back to the left auricle. This is a relatively short circulation, the blood receiving in the lungs its supply of oxygen, and there giving up some of its carbon dioxide. The greater circulation is known as the *systemic circulation;* in this system, the blood leaves the left ventricle through the great dorsal aorta. A large part of the blood passes directly to the muscles; some of it goes to the nervous system, kidneys, skin, and other organs of the body. It gives up its supply of food and oxygen in these tissues, receives the waste products of oxidation while passing through the capillaries, and returns to the right auricle through two large vessels known as the *venæ cavæ*. It requires from twenty to thirty seconds only for the blood to make the complete circulation from the ventricle back again to the starting point. This means that the entire volume of blood in the human body passes three or four thousand times a day through the various organs of the body.[1]

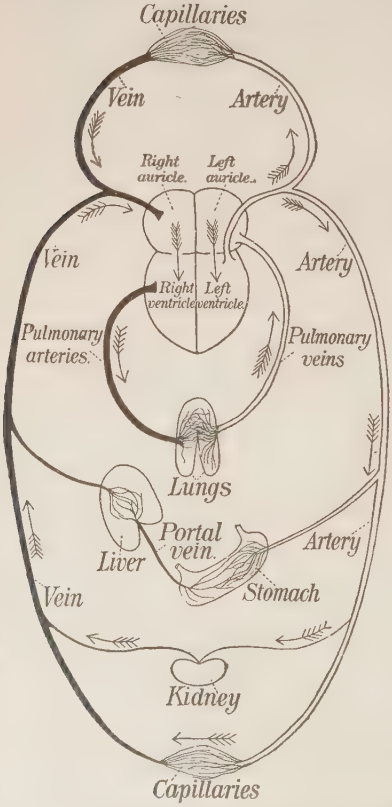


Diagram of the circulation of blood in a mammal.

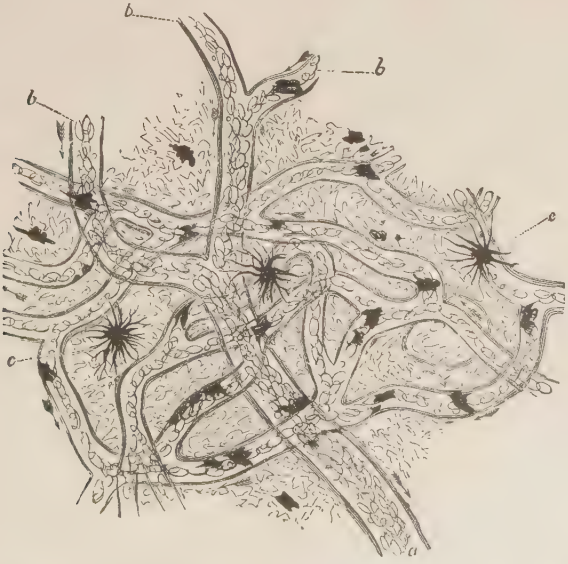
Portal Circulation. — Some of the blood, on its return to the heart, passes by an indirect path to the walls of the food tube and to its glands. From there it passes with its load of absorbed food to the liver. Here the vein which carries the blood (called the portal vein) breaks up into capillaries around the cells of the liver. We have already learned that the liver is a great storehouse of animal sugar called *glycogen*. This glycogen is a food that may be easily

[1] See Hough and Sedgwick, *The Human Mechanism*, page 136.

oxidized to release energy, and is stored for that purpose. The sugar that becomes glycogen is carried to the liver directly from the walls of the stomach and intestine, where it has been absorbed from the food there contained. From the liver, blood passes directly to the right auricle. The *portal circulation*, as it is called, is the only part of the circulation where the blood passes through two sets of capillaries.

Problem XLIX. *A study of the circulation of the blood.* (*Laboratory Manual, Prob. XLIX.*)

Circulation in the Web of a Frog's Foot. — If the web of the foot of a live frog or the tail of a tadpole is examined under the compound microscope, a network of blood vessels will be seen. In some of these the corpuscles are moving rapidly and in spurts; these are *arteries*. The arteries lead into smaller vessels hardly greater in diameter than the width of a single corpuscle. This network of *capillaries* may be followed into larger *veins* in which the blood moves regularly. This illustrates the condition in any tissue of



Capillary circulation in the web of a frog's foot, as seen under the compound microscope. *a*, *b*, small veins; *c*, pigment cells in the skin; *d*, capillaries in which the oval corpuscles are seen to follow one another in single series.

man where the arteries break up into capillaries, and these in turn form veins.

Structure of the Arteries. — A distinct difference in structure exists between the arteries and the veins in the human body. The arteries, because of the greater strain received from the blood which is pumped from the heart, have thicker muscular walls and in addition are very elastic.

Cause of the Pulse. — The *pulse*, which can easily be detected by pressing the large artery in the wrist or the small one in front of and above the external ear, is caused by the gushing of blood through the arteries after each pulsation of the heart. As the large arteries pass away from the heart, the diameter of each individual artery becomes smaller. At the very end of their course, these arteries are so small as to be almost microscopic in size and are very numerous. There are so many that if they were placed together, side by side, their united diameter would be much greater than the diameter of the large artery (*aorta*) which passes blood from the left side of the heart. This fact is of very great importance, for the force of the blood as it gushes through the arteries becomes very much less when it reaches the smaller vessels. This gushing movement is quite lost when the capillaries are reached, first, because there is so much more space for the blood to fill, and secondly, because there is considerable friction caused by the very tiny diameter of the capillaries.

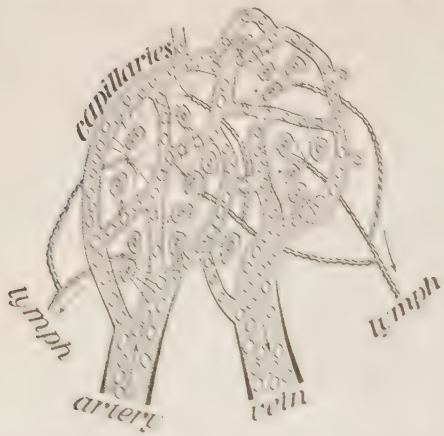
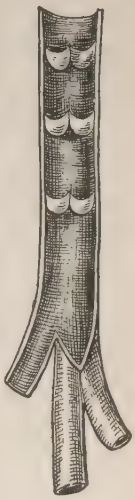


Diagram of capillary circulation. Note that the artery breaks up into smaller vessels, which unite again to form a vein. The plasma passes through the walls of the capillaries to nourish the body cells; some of the lymph then enters the lymph vessels and the rest returns to the capillaries.

Capillaries. — The capillaries form a network of minute tubes everywhere in the body, but especially near the surface and in the lungs. It is through their walls that the food and oxygen pass to the tissues, and carbon dioxide is given up to the plasma. They form the connection that completes the system of circulation of blood in the body.

Function and Structure of the Veins. — If the arteries are supply pipes which convey fluid food to the tissues, then the veins may be likened to drain pipes which carry away waste material from the tissues. Extremely numerous in the extremities and in the muscles and among other tissues of the body, they, like the branches of a tree, become larger and unite with each other as they approach the heart.



Valves in a vein. Notice the thin walls of the vein.

If the wall of a vein is carefully examined, it will be found to be neither so thick nor so tough as an artery wall. When empty, a vein collapses; the wall of an artery holds its shape. If you hold your hand downward for a little time and then examine it, you will find that the veins, which are relatively much nearer the surface than are the arteries, appear to be very much knotted. This appearance is due to the presence of tiny valves within. These valves open in the direction of the blood current, but would close if the direction of the blood flow should be reversed (as in case a deep cut severed a vein). As the pressure of blood in the veins is much less than in the arteries, the valves thus aid in keeping the flow of blood in the veins toward the heart. The higher pressure in arteries and the suction in the veins (caused by the enlargement of the chest cavity in breathing) are the chief factors which cause a steady flow of blood through the veins in the body.

Problem L. *Some changes in the composition of the blood.* (*Laboratory Manual, Prob. L.*)

Function of Lymph. — Different tissues and organs of the body are traversed by a network of tubes which carry the blood. Inside these tubes is the blood proper, consisting of a fluid plasma, the colorless corpuscles, and the red corpuscles. Outside the blood tubes, in spaces between the cells which form tissues, is found another fluid, which is in chemical composition very much like plasma of the blood. This is the *lymph*. It is, in fact, fluid food in which some colorless amœboid corpuscles are found. Blood gives

up its food material to the lymph. This it does by passing it through the walls of the capillaries. The food is in turn given up to the tissue cells which are bathed by the lymph.

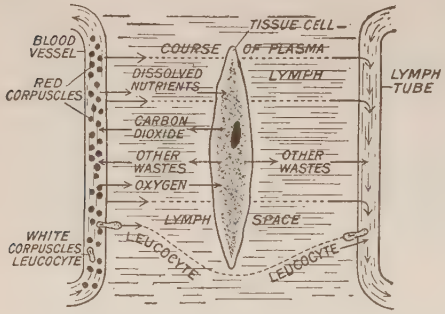


Diagram showing the exchange between blood and the cells of the body.

Some of the amœboid corpuscles from the blood make their way between the cells forming the walls of the capillaries. *Lymph, then, is practically blood-plasma plus some colorless corpuscles. It acts as the medium of exchange between the blood proper and the cells in the tissues of the body.* By means of the food supply thus brought, the cells of the body are able to grow, the fluid food being changed to the protoplasm of the cells. By means of the oxygen passed over by the lymph, oxidation may take place within the cells. Lymph not only gives food to the cells of the body, but also takes away carbon dioxide and other waste materials, which are ultimately passed out of the body by means of the lungs, skin, and kidneys.

Lymph Vessels. — The lymph is collected from the various tissues of the body by means of a number of very thin-walled tubes, which are at first very tiny, but after repeated connection with other tubes ultimately unite to form large ducts. These lymph ducts are provided, like the veins, with valves. The pressure of the blood within the blood vessels forces continually more plasma into the lymph; thus a slow current is

The lymph vessels; the dark spots are lymph glands: *lac*, lacteals; *rc*, thoracic duct.

maintained from the lymph spaces toward the veins. On its course the lymph passes through many collections of gland cells, the *lymph glands*. In these glands some impurities appear to be removed and colorless corpuscles made. The lymph ultimately passes into a large tube, the *thoracic duct*. which flows upward near the ventral side of the spinal column, and empties into the large subclavian vein in the left side of the neck. Another smaller lymph duct enters the right subclavian vein.

The Lacteals. — We have already found that part of the digested food (chiefly carbohydrates, peptones, salts, and water) is absorbed directly into the blood through the walls of the villi and carried to the liver. Fat, however, is passed into the spaces in the central part of the villi, and from there into other spaces between the tissues, known as the *lacteals*. The lacteals form the most direct course for the fats to reach the blood. The lacteals and lymph vessels have in part the same course. It will be thus seen that lymph at different parts of its course would have a very different composition.

The Nervous Control of the Heart and Blood Vessels. — Although the muscles of the heart contract and relax without our being able to stop them or force them to go faster, yet in cases of sudden fright, or after a sudden blow, the heart may stop beating for a short interval. This shows that the heart is under the control of the nervous system. Two sets of nerve fibers, both of which are connected with the central nervous system, pass to the heart. One set of fibers accelerates, the other slows or inhibits, the heartbeat. The arteries and veins are also under the control of the sympathetic nervous system. This allows of a change in the diameter of the blood vessels. Thus, blushing is due to a sudden rush of blood to the surface of the body, caused by an expansion of the blood vessels at the surface. The blood vessels of the body are always full of blood. This results from an automatic regulation of the diameter of the blood tubes by a part of the nervous system called the *vasomotor nerves*. These nerves act upon the muscles in the walls of the blood vessels. In this way, each vessel adapts itself to the amount of blood in it at a given time. After a hearty meal, a large supply of blood is needed in the walls of the stomach and intestines. At this time, the arteries going to this region are dilated so as to receive an extra supply. When the brain performs hard work, blood is supplied in the same manner to that region. Hence, one should not study or do mental work immediately after a hearty meal, for blood will be drawn away to the brain, leaving the digestive tract with an insufficient supply. Indigestion may follow as a result.

The Effect of Exercise on the Circulation. — It is a fact familiar to all that the heart beats more violently and quickly when we are doing hard work than when we are resting. Count your own pulse when sitting quietly, and then again after some brisk exercise in the

gymnasium. Exercise in moderation is of undoubted value, because it sends the increased amount of blood to such parts of the body where increased oxidation has been taking place as the result of the exercise. The best forms of exercise are those which give as many muscles as possible work — walking, out-of-door sports, any exercise that is not violent. Exercise should not be attempted immediately after eating, as this causes a withdrawal of blood from the walls of glands of the digestive tract to the muscles of the body. Neither should exercise be continued after becoming tired, as poisons are then formed in the muscles, which cause the feeling we call *fatigue*. Remember that extra work given to the heart by extreme exercise may injure it, causing possible trouble with the valves.

Treatment of Cuts and Bruises. — Blood which oozes slowly from a cut will usually stop flowing by the natural means of the formation of a clot. A cut or bruise should, however, be washed in a weak solution of carbolic acid or some other antiseptic in order to prevent bacteria from obtaining a foothold on the exposed flesh. If blood, issuing from a wound, is bright red in color and gushes in distinct pulsations, then we know that an artery has been severed. To prevent the flow of blood, a tight bandage must be tied between the cut and the heart. A handkerchief with a knot placed over the artery may stop bleeding if the cut is on one of the limbs. If this does not serve, then insert a stick in the handkerchief and twist it so as to make the pressure around the limb still greater. Thus we may close the artery until the doctor is called, who may sew up the injured blood vessel.

Stopping flow of blood from an artery by applying a tight bandage (ligature) between the cut and the heart.

The Effect of Alcohol upon the Blood. — It has recently been discovered that alcohol has an extremely injurious effect upon the colorless corpuscles of the blood, lowering their ability to fight disease germs to a marked degree. This is well seen in a comparison of deaths from certain infectious diseases in drinkers and abstainers, the percentage of mortality being much greater in the former.

Dr. T. Alexander MacNichol, in a recent address, said : —

" Massart and Bordet, Metchnikoff and Sims Woodhead, have proved that alcohol, even in every dilute solution, prevents the white blood corpuscles from attacking invading germs, thus depriving the system of the coöperation of these important defenders, and reducing the powers of resisting disease. The experiments of Richardson, Harley, Kales, and others have demonstrated the fact that one to five per cent of alcohol in the blood of the living human body in a notable degree alters the appearance of the corpuscular elements, reduces the oxygen bearing elements, and prevents their reoxygenation."

Emphasis is frequently placed on the destruction and deterioration of the leucocytes or white blood corpuscles by writers on the subject. Dr. Grosvener declares : —

" The poisoning and paralyzing influences of alcohol lead to the conclusion that the alcoholized organism presents a lessened resistance to the attacks of microörganisms. The detailed experiments of Abbot upon lower animals lean strongly toward the same conclusion. His experiments upon rabbits showed that the normal vital resistance to some organisms was markedly diminished. . . .

" Rubin as reported in *Journal of Infectious Diseases*, May 30, 1904, studied the effect of alcohol upon infectious disease as shown in rabbits. He found that the number of leucocytes was much less in alcoholized than in the control rabbits, that as soon as the leucocytes began to decrease the bacteria increased, that there existed a negative chemotoxis."

Alcohol in the stomach is rapidly absorbed and passes into the blood stream. There the strong affinity of alcohol for oxygen, which leads them to enter very rapidly into chemical combination, causes the alcohol to appropriate the oxygen of the red corpuscles of the blood, which, as we have seen, are the great oxygen carriers in the body. This tends to impoverish the blood and render it less valuable to the tissues. — Macy, *Physiology*.

The Effect of Alcohol on the Circulation. — Alcoholic drinks affect the very delicate adjustment of the nervous centers controlling the blood vessels and heart. Even very dilute alcohol acts upon the muscles of the tiny blood vessels, consequently, more

blood is allowed to enter them, and, as the small vessels are usually near the surface of the body, the habitual redness seen in the face of hard drinkers is the ultimate result.

As a result of experiments performed in 1869, Zimmerberg declares: "In the light of these experiments one is not only justified in denying to alcohol any stimulating power whatever for the heart, but, on the contrary, in declaring that it lowers the working capacity of that organ."

Dr. J. H. Kellogg, head of the Battle Creek Sanitarium, says: "The full bounding pulse usually produced by the administration of an ounce or two of brandy properly diluted, gives the impression of an increased vigor of heart action; but it is only necessary to determine the blood pressure by means of a Riva-Rocci instrument, or Gaertner's tonometer, to discover that the blood pressure is lowered instead of raised. This lowering may amount to twenty or thirty millimeters, or even more. . . . It can readily be seen, then, that the bounding pulse is not the result of increased heart vigor, but indicates rather a weakened state of the heart, combined with a dilated condition of the small vessels."

In an address before the Liverpool Medical Association, Dr. James Barr, president of the association, discussing the effects of medicinal doses of alcohol upon the circulation, remarked: "It causes dilatation of the arterioles and of all arteries well supplied with muscular fibers, owing to its paretic effect upon the vasomotor nervous system, and its direct action as a protoplasmic poison on the muscular fiber. It has a similar, though less marked, action on the cardiac muscle. From these causes the systolic blood pressure is lowered, the systolic output from the heart is diminished, and the cardiac energy is wasted in pumping blood into relaxed vessels; the large bounding pulse with comparatively short systolic period, which gives a deceptive appearance of vigor and force in the circulation, is due to the large wave in the dilated vessels."

"The first effect of diluted alcohol is to make the heart beat faster. This fills the small vessels near the surface. A feeling of warmth is produced which causes the drinker to feel that he was warmed by the drink. This feeling, however, soon passes away, and is succeeded by one of chilliness. The body temperature, at first raised by the rather rapid oxidation of the alcohol, is soon lowered by the increased radiation from the surface.

"The immediate stimulation to the heart's action soon passes away and, like other muscles, the muscles of the heart lose power and contract with less force after having been excited by alcohol." — Macy, *Physiology*.

Alcohol, when brought to act directly on heart muscle, lessens the force of the beat. It may even cause changes in the tissues, which eventually result in the breaking of the walls of a blood vessel or the plugging of a vessel with a blood clot. This condition may cause the disease known as *apoplexy*.

Effects of Tobacco upon the Circulation. — "The frequent use of cigars or cigarettes by the young seriously affects the quality of the blood. The red blood corpuscles are not fully developed and charged with their normal supply of life-giving oxygen. This causes paleness of the skin, often noticed in the face of the young smoker. Palpitation of the heart is also a common result, followed by permanent weakness, so that the whole system is enfeebled, and mental vigor is impaired as well as physical strength." — Macy, *Physiology*.

XXVII. RESPIRATION AND EXCRETION

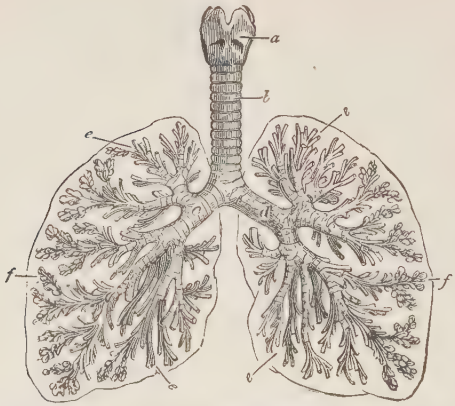
Problem LI. *A study of the organs and process of respiration.* (*Laboratory Manual, Prob. LI.*)

(*a*) *Organs of respiration in frog.*

(*b*) *Mechanics of respiration.*

(*c*) *Process of respiration in the lungs.*

Necessity for Respiration. — We have seen that plants and animals need oxygen in order that the life processes may go on. Food is oxidized to release energy, just as coal is burned to give heat to run an engine. As a draft of air is required to make fire under the boiler, so, in the human body, oxygen must be given so that foods or tissues may be oxidized to release energy used in growth. This oxidation takes place in the cells of the body, be they part of a muscle, a gland, or the brain. *Blood, in its circulation to all parts of the body, is the medium which conveys the oxygen to that place in the body where it will be used.*



Air passages in the human lungs: *a*, larynx; *b*, trachea (or windpipe); *c*, *d*, bronchi; *e*, bronchial tubes; *f*, cluster of air cells.

The Organs of Respiration in Man. — We have alluded to the fact that the lungs are the organs which give oxygen to the blood and take from it carbon dioxide. The course of air passing from the outside of the lungs in man is much the same as in the frog. Air passes through the nares, the glottis, and into the windpipe. This cartilaginous tube, the top of which may easily be felt as the Adam's apple of the throat,

divides into two *bronchi*. The bronchi within the lungs break up into a great number of smaller tubes, the *bronchial tubes*, which divide somewhat like the small branches of a tree. This branching increases the surface of the air tubes within the lungs. The bronchial tubes, indeed all the air passages, are lined with ciliated cells. The cilia of these cells are constantly in motion, beating with a quick stroke toward the outer end of the tube, that is, toward the mouth. Hence, if any foreign material should get into the windpipe or bronchial tubes, it will be expelled by the action of the cilia. It is by means of cilia that phlegm is raised from the throat. Such action is of great importance, as it prevents the filling of the air passages with foreign matter. The bronchi end in very minute air sacs called *alveoli*, — little pouches having elastic walls,— into which air is taken when we inspire or take a deep breath. In the walls of the alveoli are numerous capillaries, the ends of arteries which pass from the heart into the lung. *It is through the very thin walls of the alveoli that an interchange of gases takes place which results in the blood giving up part of its load of carbon dioxide, and taking up oxygen in its place.*

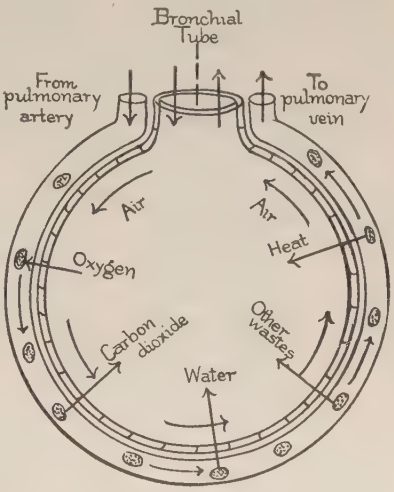


Diagram to show what the blood loses and gains in one of the air sacs of the lungs.

The Pleura. — The lungs are covered with a thin elastic membrane, the *pleura*. This forms a bag in which the lungs are hung. Between the walls of the bag and the lungs is a space filled with lymph. By this means the lungs are prevented from rubbing against the walls of the chest.

Breathing. — In every full breath there are two distinct movements, inspiration (taking air in) and expiration (forcing air out). In man an inspiration is produced by the contraction of the muscles between the ribs together with the contraction of the diaphragm, the muscular wall just below the heart and lungs; this results in pulling down the diaphragm and pulling upward and outward of the ribs, thus making the space within

the chest cavity larger. The lungs, which lie within this cavity, are filled by the air rushing into the larger space thus made. An expiration is simpler than an inspiration, for it requires no muscular effort; the muscles relax, the breastbone and ribs sink into place, while the diaphragm returns to its original position.

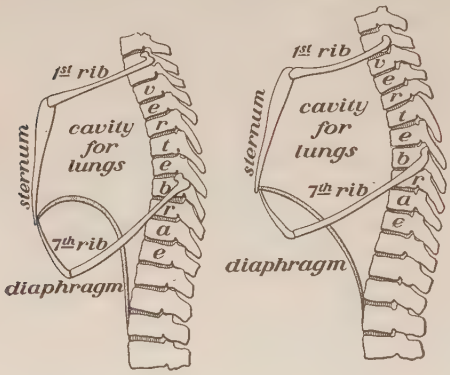
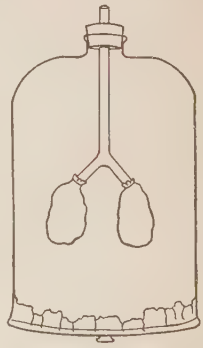


Diagram showing portion of diaphragm and ribs in (*a*) expiration; (*b*) inspiration.

A piece of apparatus which illustrates to a degree the mechanics of breathing may be made as follows: Attach a string to the middle of a piece of sheet rubber. Tie the rubber over the large end of a bell jar. Pass a glass Y tube through a rubber stopper. Fasten two small toy balloons to the branches of the tube. Close the small end of the jar with the stopper. Adjust the tube so that the balloons shall hang free in the jar. If now the rubber sheet is pulled down by means of the string, the air pressure in the jar is reduced and the toy balloons within expand, owing to the air pressure down the tube. When the rubber is allowed to go back to its former position, the balloons collapse.



Apparatus showing mechanics of breathing.

Rate of Breathing and Amount of Air Breathed. — During quiet breathing, the rate of inspiration is from fifteen to eighteen times per minute; this rate largely depends on the amount of physical work performed. About 30 cubic inches of air are taken in and expelled during the ordinary quiet respiration. The air so breathed is called *tidal air*. In a "long breath," we take in about 100 cubic inches in addition to the tidal air. This is called *complemental air*. By means of a forced expiration, it is possible to expel from 75 to 100 cubic inches more than tidal air; this air is called *reserve* air. What remains in the lungs, amounting to about 100 cubic inches, is called the *residual air*. The value of deep breathing is seen by a glance at the diagram. It is only by this means that we clear the lungs of the reserve air with its accompanying load of carbon dioxide.

Respiration under Nervous Control. — The muscular movements which cause an inspiration are partly under the control of the will, but in

part the movement is beyond our control. The nerve centers which govern inspiration are part of the sympathetic nervous system. Anything of an irritating nature in the trachea or larynx will cause a sudden expiration or cough. When a boy runs, the quickened respiration is due to the fact that oxygen is used up rapidly and a larger quantity of carbon dioxide is formed. Thus the nervous center which has control of respiration is stimulated to greater activity, and quickened inspiration follows.

Problem LII. *A study of the products of respiration.* (*Laboratory Manual, Prob. LII.*)

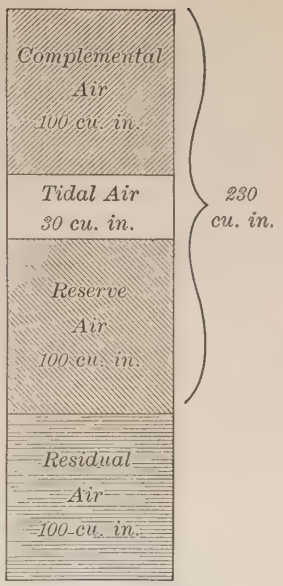


Diagram showing the relative amounts of tidal, complemental, reserve, and residual air. The brace shows the average lung capacity for the adult man.

Changes in Air in the Lungs. — Air is much warmer after leaving the lungs than before it enters them. Breathe on the bulb of a thermometer to prove this. Expired air contains a considerable amount of moisture, as may be proved by breathing on a cold polished surface. This it has taken up in the air sacs of the lungs. The presence of carbon dioxide in expired air may easily be detected by the limewater test. Air such as we breathe out of doors contains, by volume: —

Nitrogen	79
Oxygen	20.96
Carbon dioxide	.04

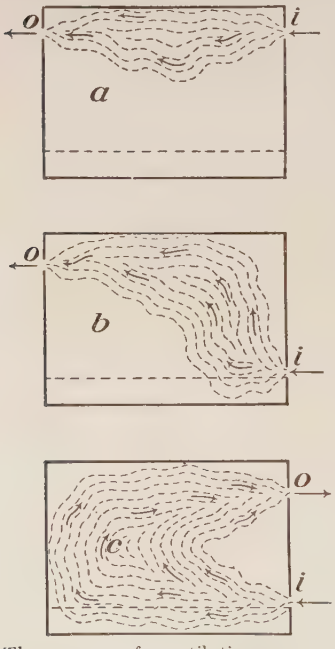
Air expired from the lungs contains: —

Nitrogen	79
Oxygen	16.02
Carbon dioxide	4.38
Water	.60

In other words, there is a loss of between four and five per cent oxygen, and nearly a corresponding gain in carbon dioxide, in expired air. There are also some other organic substances present.

The volume of carbon dioxide given off is always a little less than the volume of oxygen taken in. This seems to show that some oxygen unites with some of the chemical elements in the body.

Changes in the Blood within the Lungs. — Blood, after leaving the lungs, is much brighter red than just before entering them. The change in color is due to a taking up of oxygen by the *hæmoglobin* of the red corpuscle. Changes taking place in blood are obviously the reverse of those which take place in air in the lungs. *Blood in the capillaries within the lungs gains from four to five per cent of oxygen, which the air loses. At the same time blood loses the four per cent of carbon dioxide, which the air gains.* The water, of which about half a pint is given off daily, is mostly lost from the blood.



Three ways of ventilating a room: *i*, inlet for air; *o*, outlet for air. Which is the best method of ventilation? Explain.

Problem LIII. *A study of ventilation.* (*Laboratory Manual, Prob. LIII.*)

Need of Ventilation. — During the course of a day the lungs have lost to the surrounding air nearly two pounds of carbon dioxide. This means that about three fifths of a cubic foot is given off from each person during an hour. When we are confined for some time in a room, it becomes necessary to get rid of this carbon dioxide. This can be done only by means of proper ventilation. Other materials are passed off from the lungs with carbon dioxide. It is the presence of these wastes in combination with carbon dioxide that makes breathed air particularly unwholesome. The presence of impurities in the air of a room may easily be determined by its odor. The close smell of a poorly ventilated room is due to organic impurities given off with the carbon dioxide. This, fortunately, gives us an

index by which we may prevent poisoning. Air containing from 6 to 8 parts of carbon dioxide to 10,000 parts of air is bad; while from 12 to 14 parts in 10,000 makes a very dangerous amount. Among the factors which take oxygen from the air in a closed room and produce carbon dioxide are burning gas or oil lamps, stoves, the presence of a number of people, etc.

Proper Ventilation. — Ventilation consists in the removal of air that has been used, and the introduction of a fresh supply to take its place. If we remember that warm air is lighter than cold air, and carbon dioxide is heavier than air, we can see that ventilation outlets should be on the level of the floor. The inlets should be near the top of the room, especially in houses heated by any method of direct radiation, such as steam or hot water. A good method of ventilation for the home is to place a board two or three inches high between the lower sash and the frame of a window. An open fireplace in a room aids in ventilation because of the constant draft up the flue.

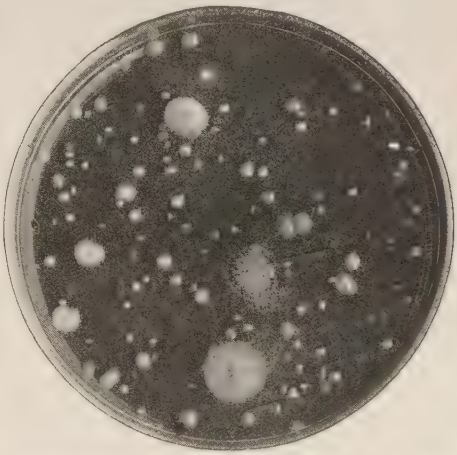


Plate culture exposed for five minutes in a school hall where pupils were passing to recitations. Each spot is a colony of bacteria or mold.

Sweeping and Dusting. — It is very easy to demonstrate the amount of dust in the air by following the course of a beam of light in a darkened room. We have already proved that spores of mold and yeast exist in the air. That bacteria are also present can be proved by exposing a sterilized gelatin plate to the air in a schoolroom for a few moments.[1]

[1] Expose two sterilized dishes containing culture media; one in a room being swept with a damp broom, and the other in a room which is being swept in the usual manner. Note the formation of colonies of bacteria in each dish. In which dish does the most growth take place?

Many of the bacteria present in the air are active in causing diseases of the respiratory tract, such as diphtheria, membranous croup, and tuberculosis. Other diseases, as colds, bronchitis (inflammation of the bronchial tubes), and pneumonia (inflammation of the tiny air sacs of the lungs), are probably caused by bacteria.

Dust, with its load of bacteria, will settle on any horizontal surface in a room not used for three or four hours. Dusting and sweeping should always be done with a damp cloth or broom, otherwise the bacteria are simply stirred up and sent into the air again. The proper watering of streets before they are swept is also an important factor in health.

Ventilation of Sleeping Rooms. — Sleeping in close rooms is the cause of much illness. Beds ought to be placed so that a constant supply of fresh air is given without a direct draft. This may often be managed with the use of screens. Bedroom windows should be thrown open in the morning to allow free entrance of the sun and air, bedclothes should be washed frequently, and sheets and pillow covers often changed. Bedroom furniture should be simple, and but little drapery allowed in the room.

Hygienic Habits of Breathing. — Every one ought to accustom himself upon going into the open air to inspire slowly and deeply to the full capacity of the lungs. A slow expiration should follow. Take care to force the air out. Breathe through the nose, thus warming the air you inspire before it enters the lungs and chills the blood. Repeat this exercise several times every day. You will thus prevent certain of the air sacs which are not often used from becoming hardened and permanently closed.

The Relation of Tight Clothing to Correct Breathing. — It is impossible to breathe correctly unless the clothing is worn loosely over the chest and abdomen. Tight corsets and tight belts prevent the walls of the chest and the abdomen from pushing outward and interfere with the drawing of air into the lungs. They may also result in permanent distortion of parts of the skeleton directly under the pressure. Other organs of the body cavity, as the stomach and intestines, may be forced downward, out of place, and in consequence do not perform their work properly.

Relation of Exercise. — We have already seen that exercise re-

sults in the need of greater food supply, and hence a more rapid pumping of blood from the heart. With this comes need of more oxygen to allow the oxidations which supply the greater energy used. Hence deeper breathing during time of exercise is a prime necessity in order to increase the absorbing surface of the lungs.

Suffocation and Artificial Respiration. — Suffocation results from the shutting off of the supply of oxygen from the lungs. It may be brought about by an obstruction in the windpipe, by a lack of oxygen in the air, by inhaling some other gas in quantity, or by drowning. A severe electric shock may paralyze the nervous centers which control respiration, thus causing a kind of suffocation. In the above cases, death often may be prevented by prompt recourse to artificial respiration. To accomplish this, place the patient on his back with the head lower than the body; grasp the arms near the elbows and draw them *upward* and *outward* until they are stretched above the head, on a line with the body. By this means the chest cavity is enlarged and an inspiration produced. To produce an expiration, carry the arms downward, and press them against the chest, thus forcing the air out of the lungs. This exercise, regularly repeated every few seconds, if necessary for hours, has been the source of saving many lives.

Common Diseases of the Nose and Throat. — Catarrh is a disease which people with sensitive mucous membrane of the nose and throat are subject to. It is indicated by the constant secretion of mucus from these membranes. Frequent spraying of the nose and throat with some mild antiseptic solutions is found useful. Chronic catarrh should be attended to by a physician. Often we find children breathing entirely through the mouth, the nose being seemingly stopped up. When this goes on for some time the nose and throat should be examined by a physician for *adenoids*, or growths of soft masses of tissue which fill up the nose cavity, thus causing a shortage of the air supply for the body. Many a child, backward at school, thin and irritable, has been changed to a healthy, normal, bright scholar by the removal of adenoids. Sometimes the tonsils at the back of the mouth cavity may become enlarged, thus shutting off the air supply and causing the same trouble as we see in a case of adenoids. The simple removal of the obstacle by a doctor soon cures this condition.

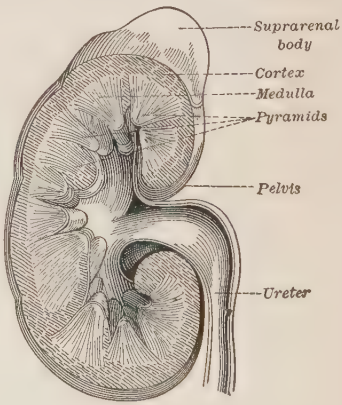
Cell Respiration. — It has been found, in the case of very simple animals, such as the *amœba*, that when oxidation takes place in a cell, work results from this oxidation. The oxygen taken into the lungs is not used there, but is carried by the blood to such parts of the body as need oxygen to oxidize food materials in the cells. The quantity of oxygen used by the body is

nearly dependent on the amount of work performed. From twenty to twenty-five ounces is taken in and used by the body every day. Oxygen is constantly taken from the blood by tissues in a state of rest and is used up when the body is at work. This is proved by the fact that in a given time a man, when working, gives off more oxygen (in carbon dioxide) than he takes in during that time.

The respiration of cells.

While work is being done certain wastes are formed in the cell. Carbon dioxide is released when carbon is burned. But when proteids are burned, another waste product containing nitrogen is formed. This must be passed off from the cells, as it is a poison. Here again the blood and lymph, common carriers, take the waste material to points where it may be *excreted* or passed out of the body.

Organs of Excretion. — All the life processes which take place in a living thing result ultimately, in addition to giving off of carbon dioxide, in the formation of organic wastes within the body. Such organic waste contains nitrogen, and in animals is usually called *urea*. In man, the skin and kidneys perform this function, hence they are called the organs of excretion.



Longitudinal section of kidney.

The Human Kidney. — The human kidney is about four inches long, two and one half inches wide, and one inch in thickness. Its color is dark red. If the structure of the medulla and cortex (see Figure above) is examined under the compound microscope, you will find these regions to be composed of a vast number of tiny branched and twisted tubules. The outer end of each of these

tubules opens into the *pelvis*, the space within the kidney; the inner end, in the cortex, forms a tiny closed sac. In each sac, the outer wall of the tube has grown inward and carried with it a very tiny artery. This artery breaks up into a mass of capillaries. These capillaries, in turn, unite to form a small vein as they leave the little sac. Each of these sacs with its contained blood vessels is called a *glomerulus*.

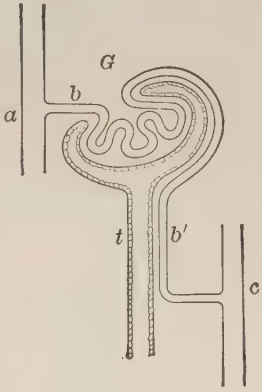


Diagram of kidney circulation, showing a glomerulus and tubule: *a*, artery bringing blood to part; *b*, capillary bringing blood to glomerulus; *b′*, vessel continuing with blood to tubule; *c*, vein; *t*, tubule; *G*, glomerulus.

Wastes given off by the Blood in the Kidney. — In the glomerulus the blood loses by osmosis, through the very thin walls of the capillaries, first, a considerable amount of water (amounting to nearly three pints daily); second, a nitrogenous waste material known as urea; third, salts and other waste organic substances, uric acid among them.

These waste products, together with the water containing them, are known as *urine*. The total amount of nitrogenous waste leaving the body each day is about twenty grams; this is nearly all accounted for in the urea passed off by the kidney, as urine is secreted in the kidney. It is passed through the *ureter* to the *urinary bladder;* from this reservoir it is passed out of the body, through a tube called the *urethra*. After the blood has passed through the glomeruli of the kidneys it is purer than in any other place in the body, because, before coming there, it lost a large part of its burden of carbon dioxide in the lungs. After leaving the kidney it has lost much of its nitrogenous waste. So dependent is the body upon the excretion of its poisonous material that, in cases where the kidneys do not do their work properly, death may ensue within a few hours.

Structure and Use of Sweat Glands. — If you examine the surface of your skin with a lens, you will notice the surface is thrown into little ridges. In these ridges may be found a large number of very tiny pits; these are the pores or openings of the sweat-secreting glands. From each opening a little tube penetrates deep within the epidermis; there, coiling around upon itself several times, it forms the sweat gland. Close around this coiled tube are

found many capillaries. From the blood in these capillaries, cells lining the wall of the gland take water, and with it a little carbon dioxide, urea, and some salts (common salt among others). This forms the excretion known as *sweat*. The combined secretions from these glands amount normally to a little over a pint during twenty-four hours. At all times, a small amount of sweat is given off, but this is evaporated or is absorbed by the underwear; as this passes off unnoticed it is called *insensible perspiration*. In hot weather or after hard manual labor the amount of perspiration is greatly increased.

Relation of Bodily Heat to Work Performed. — The bodily temperature of a person engaged in manual labor will be found to be but little higher than the temperature of the same person at rest. When a man works, he releases energy by oxidizing food material or tissue in the body. Thus we know from our previous experiments that heat is released. Muscles, nearly one half the weight of the body, release about five sixths of their energy as heat. At all times they are giving up some heat. How is it that the bodily temperature does not differ greatly at such times?

Regulation of Heat of the Body. — The temperature of the body is largely regulated by means of the activity of the sweat glands. The blood carries much of the heat, liberated in the various parts of the body by the oxidation of food, to the surface of the body, where it is lost in the evaporation of sweat. In hot weather the blood vessels of the skin are dilated; in cold weather they are made smaller by the action of the nervous system. The blood thus loses water in the skin, the water evaporates, and we are cooled off. *The object of increased perspiration, then, is to remove heat from the body.* With a large amount of blood present in the skin, perspiration is increased; with a small amount, it is diminished. Hence, we have in the skin an automatic regulator of bodily temperature.

Sweat Glands under Nervous Control. — The sweat glands, like the other glands in the body, are under the control of the sympathetic nervous system. Frequently the nerves dilate the blood vessels of the skin, thus helping the sweat glands to secrete, by giving them more blood.

" Thus regulation is carried out by the nervous system determining, on the one hand, the loss by governing the supply of blood to the skin and the

action of the sweat glands; and on the other, the production by diminishing or increasing the oxidation of the tissues." — Foster and Shore, *Physiology.*

Comparison with Cold-blooded Animals. — We have seen the bodily temperature of a frog remain nearly that of the surrounding medium. Fishes, all amphibious animals, and reptiles are alike in this respect. This change in the bodily temperature is due to the absence of regulation by the nervous system. A sort of regulation is exerted, however, by outside forces, for the cold in winter causes the cold-blooded animals to become inactive. Warm weather, on the other hand, stimulates them to greater activity and to increased oxidation. This is naturally followed by a rise in bodily temperature.

Problem LIV. *A final study of changes in the composition of blood in various parts of the body.* (*Laboratory Manual, Prob. LIV.*)

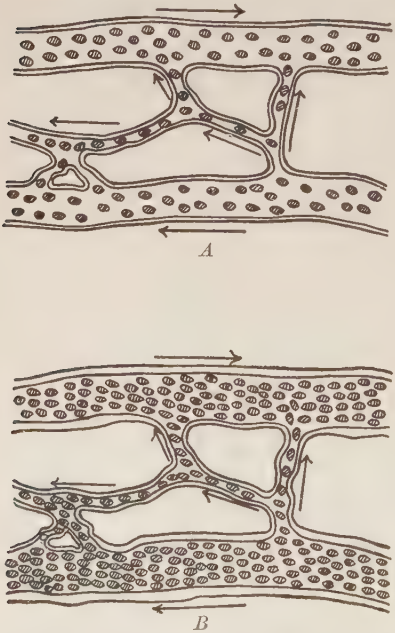
Summary of Changes in Blood within the Body. — We have already seen that red corpuscles in the lungs lose part of their load of carbon dioxide that they have taken from the tissues, replacing it with oxygen. This is accompanied by a change of color from purple (in blood which is poor in oxygen) to that of bright red (in richly oxygenated blood). Other changes take place in other parts of the body. In the walls of the food tube, especially in the small intestine, the blood receives its load of fluid food. In the muscles and other working tissues the blood gives up food and oxygen, receiving carbon dioxide and organic waste in return. In the liver, the blood gives up its sugar, and the worn-out red corpuscles which break down are removed (as they are in the spleen) from the circulation. In glands, it gives up materials used by the gland cells in their manufacture of secretions. In the kidneys, it loses water and nitrogenous wastes (*urea*). In the skin, it also loses some waste materials, salts, and water.

Hygiene of the Skin. — The skin as an organ of excretion is of importance. It is of even greater importance as a regulator of bodily temperature. The mouths of the sweat glands must not be allowed to become clogged with dirt. The skin of the entire body should, if possible, be bathed daily. For those who can stand it, a cold sponge bath is best. Soap should be used daily on parts exposed to dirt. Exercise in the open air is important to all who desire a good complexion. The body should be kept at an even

temperature by the use of proper underclothing. Wool, a poor conductor of heat, should be used in winter, and cotton, which allows of a free escape of heat, in summer.

Cuts, Bruises, and Burns. — In case the skin is badly broken it is necessary to prevent the entrance and growth of bacteria. This may be done by washing the wound with weak antiseptic solutions, such as 3 % *carbolic acid*, 3% *lysol, peroxide of hydrogen* (full strength), or a $\frac{1}{10}$ % solution of *bichloride of mercury*. These solutions should be applied immediately.

"A burn or scald should be covered at once with a paste of baking soda, which tends to lessen the pain by keeping out the air and reducing the inflammation. A mixture of linseed oil and limewater, known as carron oil, is a good remedy to keep on hand for burns." — Peabody, *Physiology*.



A, blood vessels in skin normal; *B*, when congested.

Colds and Fevers. — The regulation of blood passing through the blood vessels is under control of the nervous system. If this mechanism is interfered with in any way, the sweat glands may not do their work, perspiration may be stopped, and the heat from oxidation held within the body. The body temperature goes up, and a fever results.

If the blood vessels in the skin are suddenly cooled when full of blood, they contract and send the blood elsewhere. As a result a congestion or cold may follow. Colds are, in reality, a congestion of membranes lining certain parts of the body, as the nose, throat, windpipe, or lungs.

When suffering from a cold, it is therefore important not to chill the skin, as a full blood supply should be kept in it and so kept

from the seat of the congestion. For this reason hot baths (which call the blood to the skin), the avoiding of drafts (which chill the skin), and warm clothing are useful factors in the care of colds.

" The Bodily Heat as affected by Alcohol. — Alcohol lowers the temperature of the body by dilating the blood vessels of the skin. It does this by means of its influence on the nervous system. It is, therefore, a mistake to drink alcoholic beverages when one is extremely cold, because by means of this more bodily heat is allowed to escape.

" Because alcohol is quickly oxidized, and because heat is produced in the process, it was long believed to be of value in maintaining the heat of the body. A different view now prevails as the result of much observation and experiment. Physiologists show by careful experiments that though the temperature of the body rises during digestion of food, it is lowered for some hours when alcohol is taken. The flush which is felt upon the skin after a drink of wine or spirits is due in part to an increase of heat in the body, but also to the paralyzing effect of the alcohol upon the capillary walls, allowing them to dilate, and so permitting more of the warm blood of the interior of the body to reach the surface. There it is cooled by radiation, and the general temperature is lowered." — Macy, *Physiology.*

Effect of Alcohol on Respiration. — It has been shown that alcohol tends to congest the membranes of the organs of respiration. This it does by relaxing the membranes of the throat and lungs.

" Those who have injured themselves with alcohol show less power of resistance against influences unfavorable to health, and are carried off by diseases which other people of the same age pass through safely, especially in cases of inflammation of the lungs." — Birch-Hirschfeld.

" The action of alcohol upon the muscular walls of the arteries, which has been already more than once referred to, is especially important in the capillaries of the lungs. When they are dilated by the paralyzing effect of alcohol, their expansion reduces the size of the air cells in the lungs and leaves less room for the air which the lungs need, so that less oxygen is supplied to the blood. When the capillaries are often or continuously distended in this way, their walls are likely to become permanently thickened, and the interchange of gases which normally takes place there, by which carbon dioxide passes from the blood while the purifying oxygen is taken into the blood, is impeded. Serious disease even may result, such as a peculiar and quickly fatal form of consumption found only among drinkers of alcoholic fluids.

" Dr. Legendre, a Paris physician, has recently published, for public distribution, a leaflet, in which he says: ' Alcohol is a frequent cause of consumption by its power of weakening the lungs. Every year we see patients who attend the hospital for alcoholism come back after a period to be treated for consumption.' " — London *Lancet.*

"An American medical writer (*Journal of American Medical Association*) points out the reason why the use of alcohol makes one liable to consumption. He mentions the use of alcohol among various other things which cause the natural vital resistance of the healthy body to be impaired. Among those other things mentioned with alcohol, which produce this impairment of vital resistance, are: 'Living in overcrowded, ill-ventilated houses, on damp soils, or insufficient clothing and outdoor exercise.'" — Hall, *Elementary Physiology.*

"**Alcohol interferes with the Respiration of the Cells.** — Alcohol is quickly absorbed from the stomach and intestine and as quickly disappears. After it is taken, little or no alcohol, or any substance like alcohol, or any substance containing so little oxygen as alcohol, can be found in any waste of the body. Hence the inference is that it must be oxidized, although the exact point and the manner of its oxidation may not be known. But the evidence for its oxidation is the same as that for the oxidation of sugar.

"Every ounce of alcohol requires nearly two ounces of oxygen to oxidize it fully. Taking twenty-five ounces of oxygen gas as the amount used in a day, there will be only one ounce used in an hour. So to oxidize an ounce of alcohol takes an amount of oxygen equal to the whole supply of the body for two hours. Three or four drinks of whisky contain this ounce of alcohol. If this amount is drunk, there will soon be a lessened action and a narcotic effect throughout the body, due mainly to the lack of oxygen. A noticeable degree of uncertain action is called *intoxication.*

"Using alcohol in the body is like burning kerosene in a coal stove. By taking great care a little kerosene can be made to give out some heat from the stove, but the operation is dangerous. Some people seem to oxidize alcohol within the body with but little harm; but they run great risks of doing themselves harm, and the result is not nearly so good as if they had used proper food.

"**Effects of Tobacco on Respiration.** — Tobacco smoke contains the same kind of poisons as the tobacco, with other irritating substances added. It is usually sucked into the mouth and at once blown out again, but cigarette smoke is commonly drawn into the lungs and afterwards blown out through the nose. It is irritating to the throat, causing a cough and rendering it more liable to inflammation. If inhaled into the bronchi, it produces still greater irritation, and the vaporized nicotine is more readily absorbed if the smoke is inhaled the more deeply. Cigarettes contain the same poisons as other forms of tobacco, and often contain other poisons which are added to flavor them." — Overton, *Applied Physiology.*

"The throat, bronchial tubes, and lungs of a tobacco smoker are all liable to irritation by the poisonous smoke, and chronic inflammation is often caused. The nicotine of tobacco is a deadly poison, and in cigarettes

there are often other poisons equally dangerous to health." — Macy, *Physiology.*

Effect of Alcohol on the Kidneys. — It is said that alcohol is one of the greatest causes of disease in the kidneys. The forms of disease known as " fatty degeneration of the kidney " and " Bright's disease " are both frequently due to this cause. The kidneys are the most important organs for the removal of nitrogenous waste.

Alcohol unites more easily with oxygen than most other food materials, hence it takes away oxygen that would otherwise be used in oxidizing these foods. Imperfect oxidation of foods causes the development and retention of poisons in the blood which it becomes the work of the kidneys to remove. If the kidneys become overworked, disease will occur. Such disease is likely to make itself felt as rheumatism or gout, both of which are believed to be due to waste products (poisons) in the blood.

Dr. McMichael, in the *Dietetic and Hygienic Gazette*, says, " Alcohol produces disease of the liver and of the kidneys because these glands are most concerned in the throwing out of any poison, and are always, until they are deranged in structure, engaged in removing it from the body." He further says that the disease almost universally caused in the liver by alcohol is one in which the connective tissue framework of the liver increases, taking the place of the liver cells, until the liver is no longer able to perform its function.

The kidneys may undergo a change similar to that of the liver when alcohol is used, even in moderate amounts, for a long period.

" **Influence of Alcohol upon Excretion.** — If the waste substances constantly formed in the body are not promptly removed, they tend to poison the system. When the organism is at a high level of health, the breaking down of tissue by oxidation, which produces waste, goes on rapidly and vigorously. When this is retarded, as we have seen it to be when alcohol is introduced into the circulation and uses up the oxygen which should be applied to the oxidation of food, then the weight may increase, but it is by the retention of poisonous matter which ought to be removed. No other one cause creates so much disease of the kidneys as does the use of alcohol. Imperfect oxidation of food develops poisons which the kidneys are overtaxed to remove. This may be caused by eating too much, or by eating unwholesome food, or too much of certain kinds of food, as sugar especially; or it may be caused by alcohol. ' Fatty degeneration of the kidneys ' is a frequent result of the use of alcoholic drinks. The cells of the tissues become so altered, also, that they fail to act normally by removing only the poisonous substances, and they allow the valuable elements in the blood to be drained off with the waste. This is seen in the serious disease called ' Bright's disease ' in which the albumin which is necessary to health is excreted by the kidneys." - Macy, *Physiology.*

Poisons produced by Alcohol. - When too little oxygen enters the draft of the stove, the wood is burned imperfectly, and there are clouds

of smoke and irritating gases. So, if oxygen goes to the alcohol and too little reaches the cells, instead of carbonic acid gas, and water, and urea being formed, there are other products, some of which are exceedingly poisonous and which the kidneys handle with difficulty. The poisons retained in the circulation never fail to produce their poisonous effects, as shown by headaches, clouded brain, pain, and weakness of the body. The word "intoxication" means 'in a state of poisoning.' These poisons gradually accumulate as the alcohol takes oxygen from the cells. The worst effects come last, when the brain is too benumbed to judge fairly of their harm. It is not true that alcohol in a small amount is beneficial. A little is too much, if it takes oxygen which would otherwise be available to oxidize wholesome food.

XXVIII. THE NERVOUS SYSTEM AND ORGANS OF SENSE

Problem LV. *A study of the nervous system, reactions to stimuli, and habit formation.* (*Laboratory Manual, Prob. LV.*)

Divisions of the Nervous System. — The control of a number of activities for the attainment of a definite end is the function of the nervous system in the lowest as well as the highest of animals. In the vertebrate animals, the nervous system consists of two divisions. One includes the brain, spinal cord, the cranial and spinal nerves, which together make up the *cerebro-spinal nervous system.* The other division is called the *sympathetic nervous system.* The activities of the body are controlled from nerve centers by means of fibers which extend to all parts of the body, there ending in the muscles. The brain and spinal cord are examples of such centers, since they are largely made up of nerve cells. Small collections of nerve cells, called *ganglia*, are found in other parts of the body. These nerve centers are connected, to a greater or less degree, with the surface of the body by the nerves which serve as pathways between the end organs of touch, sight, taste, etc., and the centers in the brain or spinal cord. Thus sensation is obtained.

A nerve cell from the brain of a monkey, showing a great number of tiny protoplasmic projections or dendrites.

Nerve Cells and Fibers. — A nerve cell, like other cells in the body, is a mass of protoplasm containing a nucleus. But the body of the nerve cell is usually rather irregular in shape, and distinguished from most other cells by possessing several delicate, branched protoplasmic projections called *dendrites.* One of these processes, the *axis cylinder process*, is much longer than the others and ends in a muscle

The central cerebro-spinal nervous system.

or organ of sensation. The axis cylinder process forms the pathway over which nervous impulses travel to and from the nerve centers.

A nerve consists of a bundle of such tiny axis cylinder processes, bound together by a connective tissue. As a nerve ganglia is a center of activity in the nervous system, so a nerve cell is a center of activity which may send an impulse over this thin strand of protoplasm (the axis cylinder process) prolonged into a nerve fiber many hundreds of thousands of times the length of the cell. Some nerve cells in the human body, although visible only under the compound microscope, give rise to axis cylinder processes several feet in length.

Because some nerve fibers originate in organs that receive sensations and send those sensations to the central nervous system, they are called *sensory nerves*. Other axis cylinder processes originate in the central nervous system and pass outward as nerve fibers; such nerves produce movement of muscles and are called *motor nerves*.

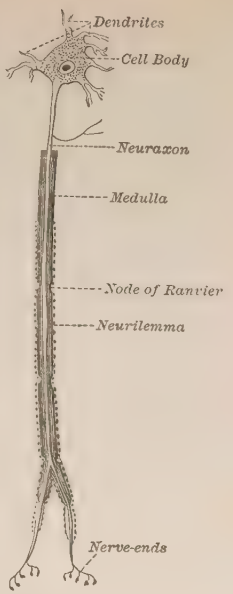
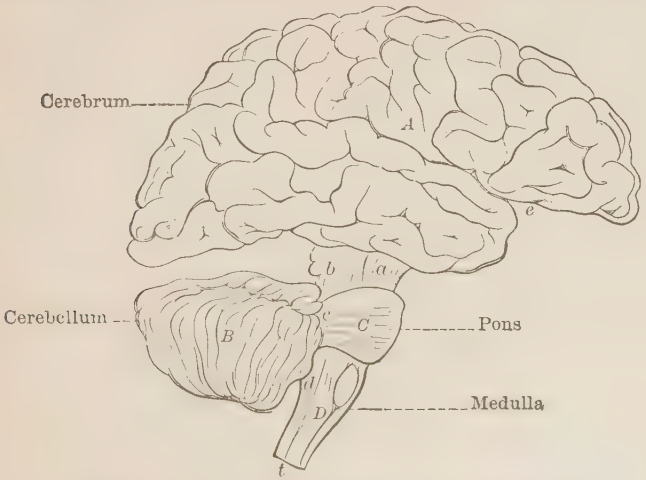


Diagram of a neuron or nerve unit.

The Brain of Man. — In man, as in the frog, the central nervous system consists of a brain and spinal cord inclosed in a bony case with the nerves leaving it. From the brain, twelve pairs of nerves are given off;



The brain, with parts separated to show each clearly.

thirty-one more leave the spinal cord. The brain has three divisions. The *cerebrum* makes up the largest part. In this respect it differs from the cerebrum of the frog and other vertebrates. It is divided into two lobes, the *hemispheres*, which are connected with each other by a broad band of nerve fibers. The outer surface of the cerebrum is thrown into folds or *convolutions*. The outer layer, seen in section, is gray in color, and is made up of nerve cells and supporting material (the *neuroglia*, a kind of connective tissue). The inner part (white in color) is composed largely of fibers which pass to other parts of the brain and down into the spinal cord. Under the cerebrum, and dorsal to it, lies the little brain, or *cerebellum*. The two sides of the cerebellum are connected by a band of nerve fibers which run around into the lower hindbrain or *medulla*. This band of fibers is called the *pons*. The medulla is, in structure, part of the spinal cord, and is made up largely of fibers running longitudinally.

Sensory and Motor Nerve Fibers. — Nerves which are connected with the central nervous system may be made up of fibers bearing messages from sense organs in the skin or elsewhere to the central nervous system, the sensory fibers, or of other fibers which carry impulses from the central nervous system to the outside, the motor fibers. Some nerves are made up of both kinds of fibers, in which case they are called mixed nerves.

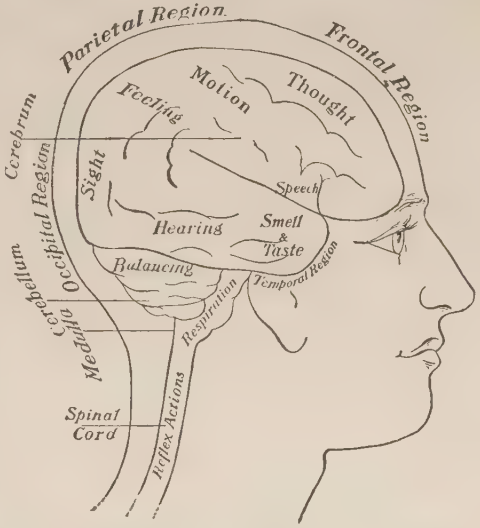
The Sympathetic Nervous System. — The sympathetic nervous system consists of a series of ganglia connected with each other and with the central nervous system through some of the spinal and cranial nerves, especially the *vagus* (tenth cranial). The sympathetic system, both in the frog and man, controls the muscles of the digestive tract and blood vessels, the secretions of gland cells, and all functions which have to do with life processes in the body.

Functions of the Parts of the Central Nervous System of the Frog. — From careful study of living frogs, birds, and some mammals we have learned much of what we know of the functions of the parts of the central nervous system in man.

It has been found that if the entire brain of a frog is destroyed and separated from the spinal cord, " the frog will continue to live but with a very peculiarly modified activity." It does not appear to breathe, nor does it swallow. It will not move or croak, but if acid is placed upon the skin so as to irritate it, the legs make movements to push away and to clean off the irritating substance. The spinal cord is thus shown to be a center for defensive movements. If the forebrain is separated from the rest of the nervous system, the frog seems to act a little differently from the normal animal. It jumps when touched, and swims when placed in water. It will croak when stroked, or swallow if food be placed in its mouth. But it manifests no hunger or fear, and is in every sense a machine which will perform certain actions after certain stimulations. Its movements are automatic. If now we watch the movements of a frog which has the brain

uninjured in any way, we find that the frog acts spontaneously. It tries to escape when caught. It feels hungry and seeks food. It is capable of voluntary action. It acts like a normal individual.

Functions of the Cerebrum. — In general, the functions of the different parts of the brain in man agree with those functions we have already observed in the frog. The cerebrum has to do with conscious activity; that is, thought. It presides over what we call our thoughts, our will, and our sensations. Each part of the area of the outer layer of the cerebrum is given over to some one of the different functions of speech, hearing, sight, touch, movements of bodily parts. The movement of the smallest part of the body has its definite localized center in the cerebrum. Experiments have been performed on monkeys, and these, together with observations made on persons who had lost the power of movement of certain parts of the body, and who, after death, were found to have had diseases localized in certain parts of the cerebrum, have given to us our knowledge on this subject.



Regions of the head and action of the different parts of the brain.

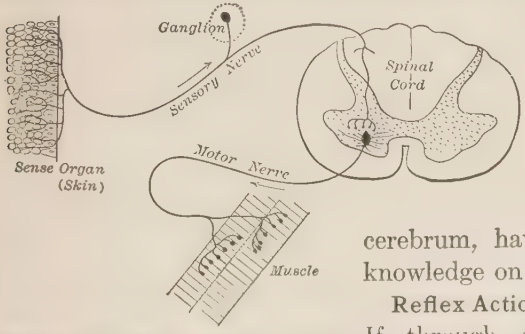


Diagram of the path of a simple nervous reflex action.

Reflex Actions; their Meaning. — If through disease or for other reasons the cerebrum does not

function, no will power is exerted, nor are intelligent acts performed. All acts performed in such a state are known as *reflex actions*. An example of a reflex may be obtained by crossing the legs and hitting the knee a sharp blow. The leg, below the knee, will fly up as a result of reflex stimulation. The involuntary brushing of a fly from the face, or the attempt to move away from the source of annoyance when tickled with a feather, are other examples. In a reflex act, a person does not think before acting. The nervous impulse comes from the outside to cells that are not in the cerebrum. The message is short-circuited back to the surface by motor nerves, without ever having reached the thinking centers. The nerve cells which take charge of such acts are located in the cerebellum or spinal cord.

Automatic Acts. — Some acts, however, are learned by conscious thought, as writing, walking, running, or swimming. Later in life, however, these activities become automatic. The actual performance of the action is then taken up by the cerebellum, medulla, and spinal ganglia. Thus the thinking portion of the brain is relieved of part of its work.

Habit Formation. — The training of the different areas in the cerebrum to do their work well is the object of education. When we learned to write, we exerted conscious effort in order to make the letters. Now the act of forming the letters is done without thought. By training, the act has become automatic. In the beginning, a process may take much thought and many trials before we are able to complete it. After a little practice, the same process may become almost automatic. We have formed a habit. Habits are really acquired reflex actions. They are the result of nature's method of training. The conscious part of the brain has trained the cerebellum or spinal cord to do certain things that, at first, were taken charge of by the cerebrum.

Importance of forming Right Habits. — Among the habits early to be acquired are the habits of studying properly, of concentrating the mind, of learning self-control, and above all, of contentment. Get the most out of the world about you. Remember that the immediate effect in the study of some subjects in school may not be great, but the cultivation of correct methods of thinking may be of the greatest importance later in life.

" The hell to be endured hereafter, of which theology tells, is no worse than the hell we make for ourselves in this world by habitually fashioning our characters in the wrong way. Could the young but realize how soon they will become mere walking bundles of habits, they would give more heed to their conduct while in the plastic state. We are spinning our own fates, good or evil, and never to be undone. Every smallest stroke of virtue or of vice leaves its never-so-little scar. The drunken Rip Van Winkle, in Jefferson's play, excuses himself for every fresh dereliction by saying, ' I won't count this time ! ' Well ! he may not count it, and a kind Heaven may not count it; but it is being counted none the less. Down among his nerve cells and fibers the molecules are counting it, registering and storing it up to be used against him when the next temptation comes. Nothing we ever do is, in strict scientific literalness, wiped out. Of course this has its good side as well as its bad one. As we become permanent drunkards by so many separate drinks, so we become saints in the moral, and authorities in the practical and scientific, spheres by so many separate acts and hours of work. Let no youth have any anxiety about the upshot of his education, whatever the line of it may be. If he keep faithfully busy each hour of the working day, he may safely leave the final result to itself. He can with perfect certainty count on waking up some fine morning, to find himself one of the competent ones of his generation, in whatever pursuit he may have singled out." — James, *Psychology*.

Necessity of Food, Fresh Air, and Rest. — The nerve cells, like all other cells in the body, are continually wasting away and being rebuilt. Oxidation of food material is more rapid when we do mental work. The cells of the brain, like muscle cells, are not only capable of fatigue, but show this in changes of form and of contents. Food brought to them in the blood, plenty of fresh air, especially when engaged in active brain work, and rest at proper times, are essential in keeping the nervous system in condition. One of the best methods of resting the brain cells is a change of occupation. Tennis, golf, baseball, and other outdoor sports combine muscular exercise with brain activity of a different sort from that of business or school work.

Necessity of Sleep. — Sleep is an essential factor in the health of the brain, especially for growing children. Most brain cells attain their growth early in life. Changes occur, however, until some time after the school age. Ten hours of sleep should be allowed for a child, and at least eight hours for an adult. At this time, only, do the brain cells have opportunity to rest and store food and energy for their working period.

The Senses

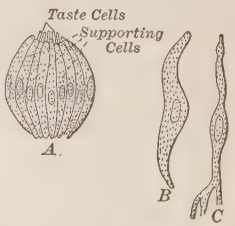
Touch. — In animals having a hard outside covering, such as certain worms, insects, and crustaceans, minute hairs, which are sensitive to touch, are found growing out from the body covering. At the base of these hairs are found nerve cells which send a nerve fiber inward to the central nervous system.

Organs of Touch. — In man, the nervous mechanism which governs touch is located in the folds of the dermis or in the skin. Special nerve endings, called the *tactile corpuscles*, are found there, each inclosed in a sheath, or capsule, of connective tissue. Inside is a complicated nerve ending, and nerve fibers pass inward to the central nervous system. The number of tactile corpuscles present in a given area of the skin determines the accuracy and ease with which objects may be known by touch.

Nerves in the skin: *a*, nerve fiber; *b*, tactile papillæ, containing a tactile corpuscle; *c*, papillæ containing blood vessels. (After Benda.)

If you test the different parts of the body, as the back of the hand, the neck, the skin of the arm, of the back, or the tip of the tongue, with a pair of open dividers, a vast difference in the accuracy with which the two points may be distinguished is noticed. On the tip of the tongue, the two points need only be separated by $\frac{1}{24}$ of an inch to be so distinguished. In the small of the back, a distance of 2 inches may be reached before the dividers feel like two points.

Temperature, Pressure, Pain. — The feeling of temperature, pressure, and pain, is determined by different end organs in the skin. Two kinds of nerve fibers exist in the skin, which give distinct sensations of heat and cold. These areas can be located by careful experimentation. There are also areas of nerve endings which are sensitive to pressure, and still others, most numerous of all, sensitive to pain.



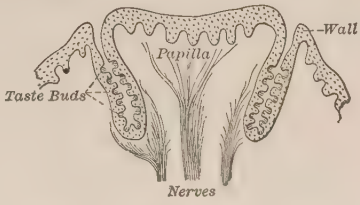
A, isolated taste bud, from whose upper free end project the ends of the taste cells; *B*, supporting or protecting cell; *C*, sensory cell.

Taste Organs. — The surface of the tongue is folded into a number of little projections known as papillæ. These may be more easily found on your own tongue if a drop of vinegar is placed on its broad surface. In the folds, between

these projections on the top and back part of the tongue, are located the organs of taste. These organs are called *taste buds*.

Each taste bud consists of a collection of spindle-shaped nerve cells, each cell tipped at its outer end with a hairlike projection. These cells send inward fibers to other cells, the fibers from which ultimately reach the brain. The sensory cells are surrounded by a number of protecting cells which are arranged in layers about them. Thus the organ in longitudinal section looks somewhat like an onion cut lengthwise.

How we Taste. — Four kinds of substances may be distinguished by the sense of taste. These are sweet, sour, bitter, and salt. Certain taste cells located near the back of the tongue are stimulated only by a bitter taste. Sweet substances are perceived by cells near the tip of the tongue, sour substances along the sides, and salt about equally all over the surface. A substance must be dissolved in fluid in order to be tasted. Many things which we believe we taste are in reality perceived by the sense of smell. Such are spicy sauces and flavors of meats and vegetables. This may easily be proved by holding the nose and chewing, with closed eyes, several different substances, such as an apple, an onion, and a raw potato.



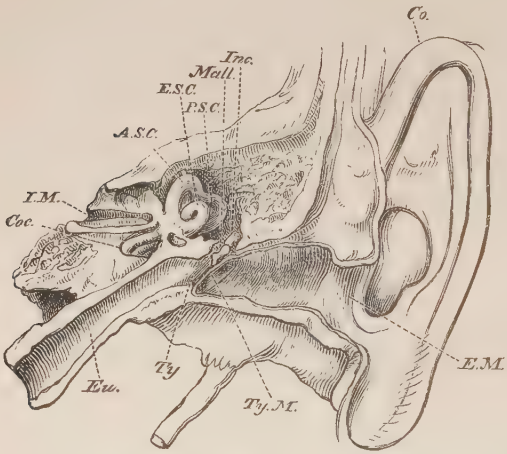
Section of circumvallate papilla.

Smell. — The sense of smell is located in the membrane lining the upper part of the nose. Here are found a large number of rod-shaped cells which are connected with the forebrain by means of the olfactory nerve. In order to perceive odors, it is necessary to have them diffused in the air; hence we sniff so as to draw in more air over the olfactory cells.

The Organ of Hearing. — The organ of hearing is the ear. In the fish, frog, and reptile, the outer ear, so prominent in man, is entirely lacking. The outer ear consists of a funnel-like organ composed largely of cartilage which is of use in collecting sound waves. This part of the ear incloses the auditory canal, which is closed at the inner end by a tightly stretched membrane, the *tympanic membrane*. We have seen the tympanic membrane of the frog on the outer surface of the head. The function of the tympanic membrane is to receive sound waves, for all sound is caused by vibrations in the air, these vibrations being transmitted, by the means of a complicated apparatus found in the middle ear, to the real organ of hearing located in the inner ear.

Middle Ear. — The middle ear in man is a cavity inclosed by the temporal bone, and separated from the outer ear by the tympanic membrane. A little tube called the *Eustachian tube* connects the inner ear with the mouth cavity. By allowing air to enter from the mouth, the air pressure is equalized on the ear drum. For this reason, we open the mouth at the

time of a heavy concussion and thus prevent the rupture of the delicate tympanic membrane. Placed directly against the tympanic membrane and connecting it with another membrane, separating the middle from the inner ear, is a chain of three tiny bones, the smallest bones of the body. The outermost is called the *hammer;* the next the *incus*, or *anvil;* the third the *stirrup*. All three bones are so called from their resemblances in shape to the articles for which they are named. These bones are held in place by very small muscles which are delicately adjusted so as to tighten or relax the membranes guarding the middle and inner ear.



Section of ear: *E.M.*, auditory canal; *Ty.M.*, tympanic membrane; *Eu.*, Eustachian tube; *Ty*, middle ear; *Coc.*, *A.S.C.*, *E.S.C.*, etc., internal ear.

The Inner Ear. — The inner ear is one of the most complicated, as well as one of the most delicate, organs of the body. Deep within the temporal bone there are found two parts, one of which is called, collectively, the *semicircular canal region*, the other the *cochlea*, or organ of hearing. Both of these organs consist of membranous bags lying in a fluid which partially fills the bony cavity which incloses them. These membranous structures themselves also contain a fluid. The semicircular canals are connected with the cochlea on one side, and are separated from the middle ear only by a membrane and the fluid which surrounds them. There are three semicircular canals, delicate membranous bags lying in a watery fluid and surrounded by bone.

It has been discovered by experimenting with fish, in which the semicircular canal region forms the chief part of the ear, that this region has to do with the equilibrium or balancing of the body. We gain in part our knowledge of our position and movements in space by means of the semicircular canals.

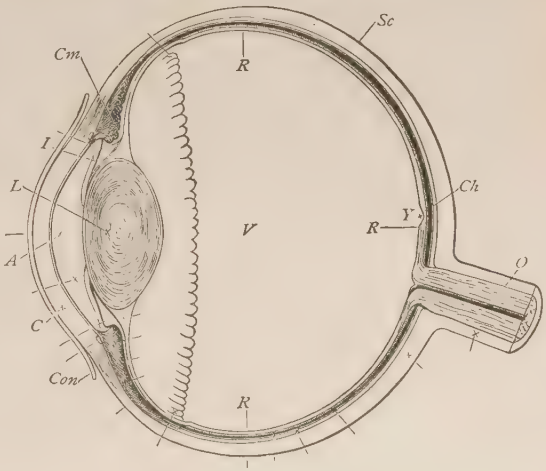
That part of the ear which receives sound waves is known as the *cochlea*, or snail shell, because of its shape. This very complicated organ is lined with sensory cells provided with cilia. The cavity of the cochlea is filled with a fluid. It is believed that somewhat as a stone thrown into water causes ripples to emanate from the spot where it strikes, so sound waves

are transmitted by means of the fluid filling the cavity to the sensory cells of the cochlea (collectively known as the *organ of Corti*) and thence to the brain by means of the auditory nerve.

The Character of Sound. — When vibrations which are received by the ear follow each other at regular intervals, the sound is said to be musical. If the vibrations come irregularly, we call the sound a noise. If the vibrations come slowly, the pitch of the sound is low; if they come rapidly, the pitch is high. The ear is able to perceive as low as thirty vibrations per second and as high as almost thirty thousand. The ear can be trained to recognize sounds which are unnoticed in untrained ears.

The Eye. — The eye or organ of vision is an almost spherical body which fits into a socket of bone, the *orbit*. A stalklike structure, the *optic nerve*, connects the eye with the brain. Free movement is obtained by means of six little muscles which are attached to the outer coat, the *eyeball*, and to the bony socket around the eye.

The wall of the eyeball is made up of three coats. An outer tough white coat, of connective tissue, is called the *sclerotic coat;* this coat is lacking in the exposed part of the eyeball, but may be seen by lifting the eyelid. Under the sclerotic coat, in front, the eye bulges outward a little. Here the outer coat is replaced by a transparent tough layer called the *cornea*. A second coat, the *choroid*, is supplied with blood vessels and cells which bear pigments. It is a part of this coat which we see through the cornea as the colored part of the eye (the *iris*). In the center of the iris is a small circular hole (the *pupil*). The iris is under the control of muscles, and may be adjusted to varying amounts of light, the hole becoming larger in dim light, and smaller in bright light. The inmost layer of the eye is called the *retina*. This is, perhaps, the most delicate layer in the entire



Longitudinal section through the eye: *Sc*, sclerotic coat; *Ch*, choroid; *O*, optic nerve; *C*, cornea; *I*, iris; *Con*, conjunctiva; *R*, retina; *Y*, yellow spot; *L*, lens; *A*, anterior chamber, filled with aqueous humor; *V*, posterior chamber, filled with vitreous humor.

body. Despite the fact that the retina is less than $\frac{1}{50}$ of an inch in thickness, there are several layers of cells in its composition. The optic nerve enters the eye from behind and spreads out over the surface of the retina. Its finest fibers are ultimately connected with numerous elongated cells which are stimulated by light. The retina is dark purple in color, this color being caused by a layer of cells next to the choroid coat. This accounts for the black appearance of the pupil of the eye, when we look through the pupil into the darkened space within the eyeball. The retina acts as the sensitized plate in the camera, for on it are received the impressions which are transformed and sent to the brain as sensations of sight. The eye, like the camera, has a lens. This lens is formed of transparent, elastic material. It is found directly behind the iris and is attached to the choroid coat by means of delicate ligaments. In front of the lens is a small cavity filled with a watery fluid, the *aqueous humor*, while behind it is the main cavity of the eye, filled with a transparent, almost jellylike, *vitreous humor*. The lens itself is elastic. This circumstance permits of a change of form and, in consequence, a change of focus upon the retina of the lens. By means of this change in form, or *accommodation*, we are able to distinguish between near and distant objects.

Diagram showing how the lens changes its form.

Defects in the Eye. — In some eyes, the lens is in focus for near objects, but is not easily focused upon distant objects; such an eye is said to be

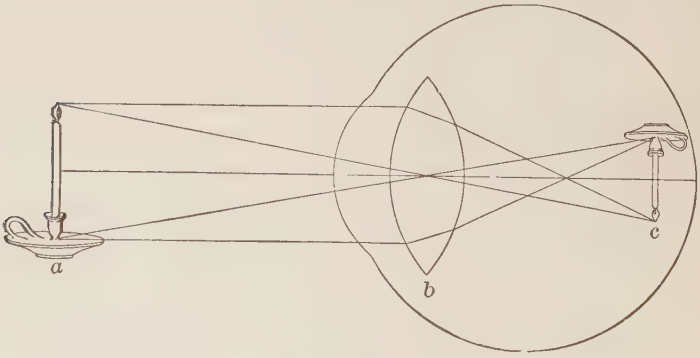


Diagram to show how an image is formed in the eye: *a*, object; *b*, lens; *c*, image upon retina.

nearsighted. Other eyes which do not focus clearly on objects near at hand are said to be farsighted. Still another eye defect is astigmatism, which causes images of lines in a certain direction to be indistinct, while

images of lines transverse to the former are distinct. Many nervous troubles, especially headaches, may be due to eye strain. We had better have our eyes examined from time to time, especially if we have headaches.

How we See. — Suppose an object be held in front of the eye; rays of light pass from every part of the object and are brought to a focus on the retina by means of the transparent lens. You can form an object in the same manner by using a reading glass, a box with a hole in one end, and a piece of white paper. Notice that the image is inverted. The same is true of the image on the retina. By means of this image thrown on the sensory layer, the rod and cone cells of the retina are stimulated and the image is transmitted to the forebrain. We must remember that the optic nerve crosses under the brain so that images formed in the right eye are received by the left half of the forebrain, and *vice versa*.

The Paralyzing Effects of Alcohol on the Nervous System. — Alcohol has the effect of temporarily paralyzing the nerve centers. The first effect is that of exhilaration. A man may do more work for a time under the stimulation of alcohol. This stimulation, however, is of short duration and is invariably followed by a period of depression and inertia. In this latter state, a man will do less work than before. In larger quantities, alcohol has the effect of completely paralyzing the nerve centers. This is seen in the case of a man "dead drunk." He falls in a stupor because all of the centers governing speech, sight, locomotion, etc., have been temporarily paralyzed. If a man takes a very large amount of alcohol, even the nerve centers governing respiration and circulation may become poisoned, and the victim will die.

In an article in the *Journal of Inebriety*, Dr. J. W. Grosvener of Buffalo says: "Alcohol is a paralyzer. The truth of this proposition has been demonstrated experimentally scores of times by world-famed physiologists. Says Forel: 'Through all parts of nervous activity from the innervation of the muscles and the simplest sensation of the highest activity of the soul the paralyzing effect of alcohol can be demonstrated.' Several experimenters of undoubted ability have noted the paralyzing effect of alcohol even in small doses. By the use of delicate instruments of precision, Ridge tested the effect of alcohol on the senses of smell, vision, and muscular sense of weight. He found that two drams of absolute alcohol produced a positive decrease in the sensitiveness of the nerves of feeling, that so small a quantity as one-half dram of absolute alcohol diminished the power of vision and the muscular sense of weight. Kraepelin and Kurz by experiment determined that the acuteness of the special senses of sight, hearing, touch, taste, and smell was diminished by an ounce of alcohol, the power of vision being lost to one third of its extent and a similar effect being produced on the other special senses. Other investigators, as Crothers, Madden, Kellogg, Frey, Von Bunge, have reached like conclusions."

It is agreed by investigators that in large or continued amounts alcohol has a narcotic effect; that it first dulls or paralyzes the nerve centers which control our judgment, and later acts upon the so-called motor centers, those which control our muscular activities.

The reason then that a man in the first stages of intoxication talks rapidly and sometimes wittily, is because the centers of judgment are paralyzed. This frees the speech centers from control exercised by our judgment, with the resultant rapid and free flow of speech.

In small amounts alcohol is believed by some physiologists to have always this same narcotic effect, while other physiologists think that alcohol does stimulate the brain centers, especially the higher centers, to increased activity. Some scientific and professional men use alcohol in small amounts for this stimulation and report no seeming harm from the indulgence. Others, and by far the larger number, agree that this stimulation from alcohol is only apparent and that even in the smallest amounts alcohol has a narcotic effect.

The Relation of Alcohol to Disease. — One of the most serious effects of alcohol is the lowered resistance of the body to disease. It has been proved that a much larger proportion of hard drinkers die from infectious or contagious diseases than from special diseased conditions due to the direct action of alcohol on the organs of the body. This lowered resistance is shown in increased liability to contract disease and increased severity of the disease.

But many cases of illness are directly due to the action of alcohol on the tissues. "Such chronic diseased conditions arise from the gradual poisoning of the system by the continued use of beverages containing alcohol. Even though we admit that alcohol in a definite small amount is, in some cases at least, fully oxidized in the body, like the carbohydrates, and so supplies energy as food, we must never forget that different constitutions may be differently affected, and conditions as to climate, temperament, and habits of life may cause variations in its influence upon health and character. We can never know perfectly the nature of all the innumerable strains of hereditary tendency which unite to make an individual what he is. Some one of these may have impressed upon the nerve cells an instability, a weakness, a peculiar susceptibility to the influence of alcohol, so that the first taste may arouse the insatiable craving which leads to dipsomania. In another case, the inherited weakness may render the child of an inebriate an epileptic, an imbecile, or a consumptive. We can never foresee just how the transmitted nervous weakness will manifest itself, but as a rule the descendants of those whose systems are poisoned by alcohol are enfeebled in body or mind or both.

"But suppose a man to have derived from his ancestors a sound constitution and to have become addicted to the moderate use of alcohol; the insidious nature of the dangerous substance may gradually lead him to consume, insensibly perhaps, only a little more than the cells can oxidize.

Without realizing it, he may slowly poison his system. The primary effect is upon the brain; there is congestion and overexcitement of the nerve cells there — conditions which gradually extend to the nerve cells of the spinal cord; inflammation sets in, and there follows fibrous degeneration of the tissues, substituting an inferior form for the specialized tissues which do the work of the organs in various parts of the body. Paralysis may result, or epilepsy, or dyspepsia from lack of the due amount of nervous influence upon the digestive organs, or any one of a thousand forms of disorder, some of which have been mentioned in preceding chapters. Though a man may never drink to intoxication, and never realize that he is using alcohol to excess, he may nevertheless become seriously diseased in consequence of his moderate indulgence, or what he believes to be such, while wondering why he is not well and strong. Still less does he consider the legacy of evil which he may be laying up for his children." — Macy, *Physiology*. (See Laboratory Manual, Prob. LVI.)

Effect of Alcohol on Ability to do Work. — In *Physiological Aspects of the Liquor Problem*, Professor Hodge of Clark University describes many of his own experiments showing the effect of alcohol on animals. He trained four selected puppies to recover a ball thrown across a gymnasium. To two of the dogs he gave food mixed with dietetic doses of alcohol, while the others were fed normally. The ball was thrown 100 feet as rapidly as recovered. This was repeated 100 times each day for fourteen successive days. Out of 1400 times the dogs to which alcohol had been given brought back the ball only 478 times, while the others secured it 922 times.

Dr. Parkes experimented with two gangs of men, selected to be as nearly similar as possible, in mowing. He found that with one gang abstaining from alcoholic drinks and the other not, the abstaining gang could accomplish more. On transposing the gangs the same results were repeatedly obtained. Similar results were obtained by Professor Aschaffenburg of Heidelberg University, who found experimentally that men "were able to do 15 per cent less work after taking alcohol." Professor Abel of Johns Hopkins University says, "Both science and the experience of life have exploded the pernicious theory that alcohol gives any persistent increase of muscular power."

The Effect of Alcohol upon Intellectual Ability. — With regard to the supposed quickening of the mental processes Horsley and Sturge, in their recent book, *Alcohol and the Human Body*, say: "Kraepelin found that the simple reaction period, by which is meant the time occupied in making a mere response to a signal, as, for instance, to the sudden appearance of a flag, was, after the ingestion of a small quantity of alcohol ($\frac{1}{4}$ to $\frac{1}{2}$ ounce), slightly accelerated; that there was, in fact, a slight shortening of the time, as though the brain were enabled to operate more quickly than before. But he found that after a few minutes, in most cases, a slowing of mental action began, becoming more and more marked, and enduring as long as the alcohol was in active operation in the body, *i.e.*

four to five hours. . . . Kraepelin found that it was only more or less automatic work, such as reading aloud, which was quickened by alcohol, though even this was rendered less trustworthy and accurate." Again: "Kraepelin had always shared the popular belief that a small quantity of alcohol (one to two teaspoonfuls) had an accelerating effect on the activity of his mind, enabling him to perform test operations, as the adding and subtracting and learning of figures more quickly. But when he came to measure with his instruments the exact period and time occupied, he found, to his astonishment, that he had accomplished these mental operations, not more, but less, quickly than before. . . . Numerous further experiments were carried out in order to test this matter, and these proved that *alcohol lengthens the time taken to perform complex mental processes*, while by a singular illusion the person experimented upon imagines that his psychical actions are rendered more rapid."

Professor Woodhead says, "After careful examination of the whole question, physiologists — and among physiologists I include those who maintain alcohol may be useful, as well as those who hold that it is harmful — have come to the conclusion that the principal action of alcohol is to blunt sensation, and to remove what we may call the power of inhibition by blunting the higher centers of the brain."

Professor David Starr Jordan in the *Popular Science Monthly*, February, 1898, said: "The healthy mind stands in clear and normal relations with nature. It feels pain as pain. It feels action as pleasure. The drug which conceals pain or gives false pleasure when pleasure does not exist forces a lie upon the nervous system. The drug which disposes to reverie rather than to work, which makes us feel well when we are not well, destroys the sanity of life. All stimulants, narcotics, tonics, which affect the nervous system in whatever way, reduce the truthfulness of sensation, thought, and action. Toward insanity all such influences lead; and their effect, slight though it be, is of the same nature as mania. The man who would see clearly, think truthfully, and act effectively must avoid them all. Emergency aside, he cannot safely force upon his nervous system even the smallest falsehood."

Dr. Hammond said: "The more purely intellectual qualities of the mind rarely escape being involved in the general disturbance [caused by alcohol]. The power of application, of appreciating the bearing of facts, of drawing distinctions, of exercising the judgment aright, and even of comprehension, are all more or less impaired. The memory is among the first faculties to suffer. . . . The will is always lessened in force and activity. The ability to determine between two or more alternatives, to resolve to act when action is necessary, no longer exists in full power, and the individual becomes vacillating, uncertain, the prey to his various passions, and to the influence of vicious counsels."

"Finally we have still to declare that alcohol hinders the action of the highest mental faculties. A remark made by Helmholtz at the celebration

of his seventieth birthday is very interesting in this connection. He spoke of the ideas flashing up from the depths of the unknown soul, that lies at the foundation of every truly creative intellectual production, and closed his account of their origin with these words: 'The smallest quantity of an alcoholic beverage seemed to frighten these ideas away.'" — Dr. G. Sims Woodhead, Professor of Pathology, Cambridge University, England.

"Some people imagine that after the use of alcohol they can do things more quickly, that they are brisker and sharper, but exact measurement shows that they are slower and less accurate. Men believe that they are wiser and brighter, but their sayings are more automatic and apt to be profane. To quote Dr. Lauder Brunton, of Oxford University, England, '*It produces progressive paralysis of the judgment*,' and this begins with the first glass. Men say and do, even after a single glass of drink, what they would not say or do without it, and therefore it clearly affects the brain and diminishes self-control." —Adolph Fick, Professor of Physiology, Würzburg, Germany.

Professor Von Bunge (*Textbook of Physiological and Pathological Chemistry*) of Switzerland says that: "The stimulating action which alcohol appears to exert on the brain functions is only a paralytic action. The cerebral functions which are first interfered with are *the power of clear judgment and reason.* No man ever became witty by aid of spirituous drinks. The lively gesticulations and useless exertions of intoxicated people are due to paralysis, — the restraining influences, which prevent a sober man from uselessly expending his strength, being removed."

"The capital argument against alcohol, that which must eventually condemn its use, is this, that *it takes away all the reserved control, the power of mastership, and therefore offends against the splendid pride in himself or herself, which is fundamental in every man or woman worth anything.*" — — Dr. John Johnson, quoting Walt Whitman.

The Drink Habit. — The harmful effects of alcohol (aside from the purely physiological effect upon the tissues and organs of the body) are most terribly seen in the formation of the alcohol habit. The first effect of drinking alcoholic liquors is that of exhilaration. After the feeling of exhilaration is gone, for this is a temporary state, the subject feels depressed and less able to work than before he took the drink. To overcome this feeling, he takes another drink. The result is that before long he finds a habit formed from which he cannot escape. With body and mind weakened, he attempts to break off the habit. But meanwhile his will, too, has suffered from overindulgence. He has become a victim of the drink habit!

Self-indulgence, be it in gratification of such a simple desire as that for candy or the more harmful indulgence in tobacco or alcoholic beverages, is dangerous — not only in its immediate effects on the tissues and organs, but in its more far-reaching effects on habit formation.

"**Self-control *versus* Appetite.** — Man is a bundle of appetites. Every organ, every cell even, craves its appropriate stimulus. Animals under natural conditions gratify the appetites as they arise only to that extent which is healthful for the whole body. Man alone, whose highly developed brain is overlord to the rest of his system, permits an unwholesome indulgence of appetite to interfere with this general well-being. Alcohol, opium, and their like are far from being the only substances whose excessive use injures the organism and degrades character. Children are often allowed to indulge a natural fondness for sweets to an extent which is ruinous to digestion; for sugar, which is a useful and necessary food in suitable quantities, becomes in larger ones a poison to the system. Boys pampered with dainties from infancy logically infer that a fancy for cigars or beer may be similarly gratified. Appetite for even the most wholesome food may be in excess of bodily needs, and the practice of gluttony is certain to derange nutrition.

"A child should be early taught that because he 'likes' a certain article of food he should not therefore continue to eat it after natural hunger is satisfied, or at times when he does not need food; while to persist in eating or drinking that which experience, or the advice of those competent to judge, has taught him to be harmful, should be regarded as unworthy a rational being." — Macy, *Physiology*.

The Moral, Social, and Economic Effect of Alcoholic Poisoning.— In the struggle for existence, it is evident that the man whose intellect is the quickest and keenest, whose judgment is most sound, is the man who is most likely to succeed. The paralyzing effect of alcohol upon the nerve centers must place the drinker at a disadvantage. In a hundred ways, the drinker sooner or later feels the handicap that the habit of drink has imposed upon him. Many corporations, notably several of our greatest railroads (the New York Central Railroad among them), refuse to employ any but abstainers in positions of trust. Few persons know the number of railway accidents due to the uncertain eye of some engineer who mistook his signal, or the hazy inactivity of the brain of some train dispatcher who, because of drink, forgot to send the telegram that was to hold the train from wreck.

In business and in the professions, the story is the same. The abstainer wins out over the drinking man.

Not alone in activities of life, but in the length of life, has the abstainer the advantage. Figures presented by life insurance companies show that the nondrinkers have a considerably greater chance of long life than do drinking men. So decided are these figures that several companies have lower premiums for the nondrinkers than for the drinkers who insure with them.

" **Other Narcotics in Common Use.** — Narcotics are very widely used by the human family for the relief which they give from pain or fatigue, or for the direct pleasurable sensations which they impart. All are deadly poisons when taken in sufficient quantities. Those most common (after alcohol) are *tobacco* and *opium.*

" It has already been shown that tobacco may affect unfavorably many parts of the system, and is especially injurious to the young. It stimulates in small quantities and narcotizes in larger ones, working its effects directly upon the nervous system. *Nicotine,* the powerful poison found in tobacco, affects the nerve cells, injures the brain, and leads especially to weakness of the heart by interfering with its supply of nervous force. Many cases of cancer of mouth and throat are believed to have resulted from tobacco smoking.

" **Opium,** for its benumbing influence upon the nerves, is used by large numbers of persons, especially in Oriental lands. Its continued use deranges all the digestive processes, disorders the brain, and weakens and degrades the character. Like alcohol, it produces an intolerable craving for itself, and the strongest minds are not proof against the deadly appetite."

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Hough and Sedgwick, *The Human Mechanism.* Ginn and Company. See also references given at the end of Chapter XXIII.

XXIX. HEALTH AND DISEASE — A CHAPTER ON CIVIC BIOLOGY

Problem LVI. *A study of personal and civic hygiene.* (*Laboratory Manual, Prob. LVI.*)

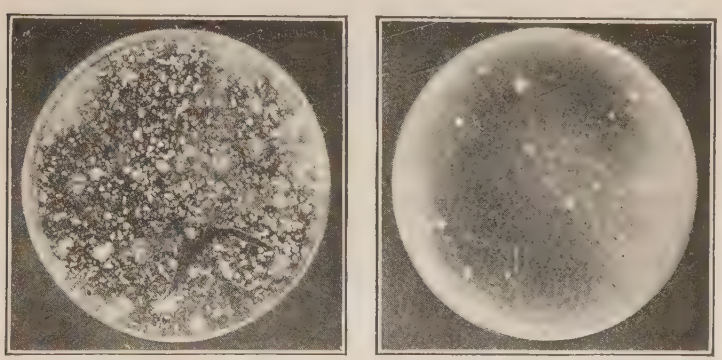
Health and Disease. — In previous chapters we have considered the body as a machine more delicate in its organization than the best-built mechanism made by man. In a state of health this human machine is in a good condition; disease is a condition in which some part of the body is out of order, thus interfering with the smooth running of the mechanism.

Personal Hygiene. — It is the purpose of the study of hygiene to show us how to live so as to keep the body in a healthy state. Hygiene not only prescribes certain laws for the care of the various parts of the body, — skin, teeth, the food tube or the sense organs, — but it also shows us how to avoid disease. The foundation of health later in life is laid down at the time we are in school; for that reason, if for no other, a knowledge of the laws of hygienic living are necessary for all school children. Unlike the lower animals, we can change or modify our immediate surroundings so as to make them better and more hygienic places to live in. Hygienic living in our home must go hand in hand with sanitary conditions around us. It is the purpose of this chapter to show how we do our share to coöperate with those in charge of the public health in our towns and cities.

Some Methods of Prevention of Disease. — The proverb "An ounce of prevention is worth a pound of cure" has much truth in it. Disease is largely preventable. Fresh air, the needed amount of sleep, moderate exercise, and pure food and water are *essentials* in hygienic living and in escape from disease.

Pure Air Needed. — What do we mean by fresh air, and why do we need it? We have already seen that oxidation takes place within the body, and that air, whose carbon dioxide is increased to 8 or 10 parts in 10,000 parts of air, by respiration, is bad for breathing.

In addition to the carbon dioxide, water and heat are given off as well as a very small amount of organic material of a poisonous nature. It is the presence of this material that gives rise to the odor noticeable in a close room. But other organic material is found in air. Dust from the street contains bacteria of all kinds, some of which may be disease-producing. Thus may be spread bacteria from the respiratory tracts of people who have colds, pneumonia, diphtheria, or tuberculosis. Much dust is dried



A. *B.*

Two cultures (*A*) were exposed to the air of a dirty street in the crowded part of Manhattan. (*B*) was exposed to the air of a well-cleaned and watered street in the uptown residence portion. Which culture has the most colonies of bacteria? How do you account for this?

excreta of animals. Soft-coal smoke does its share to add to the impurities of the air, while sewer gas and illuminating gas are frequently found in sufficient quantities to poison people. Pure air is, as can be seen, almost an impossibility in a great city.

How to get Fresh Air. — As we know, green plants give off in the sunlight considerable more oxygen than they use, and they use up carbon dioxide. The air in the country is naturally purer than in the city, as smoke and bacteria are not so prevalent there, and the plants in abundance give off oxygen. In the city the night air is purer than day air, because the factories have stopped work, the dust has settled, and fewer people are on the streets. The old myth of "night air" being injurious has long since been exploded, and thousands of people of delicate health, especially

those who have weak throat or lungs, are regaining health by sleeping out of doors or with the windows wide open. The only essential in sleeping out of doors or in a room with a low temperature is that the body be kept warm and the head be protected from strong drafts by a nightcap or hood. Proper ventilation at *all* times is one of the greatest factors in good health.

Change of Air.—Persons in poor health, especially those having tuberculosis, are often cured by a change of air. This is not always so much due to the composition of the air as to change of occupation, rest, and good food. Mountain air is dry, and relatively free from dust and bacteria, and often helps a person having tuberculosis. Air at the seaside is beneficial for some forms of disease, especially hay fever and bone tuberculosis. Many sanitariums have been established for this latter disease near the ocean, and thousands of lives are being annually saved in this way.

The Relation of Pure Food and Pure Water to Health. — Thanks to the care of state and city governments there is little need nowadays for the health of any individual to suffer from impure food or water. But that people do become sick and die from such causes every day is well known, as is shown by the many cases of typhoid fever, summer complaint, and ptomaine poisoning of various sorts. Our milk may have been watered or sent in cans washed with water containing typhoid germs, we may eat oysters bred in contaminated localities, we may have received and eaten fruits or vegetables sprinkled with water containing the germs. Our laws, however good, cannot cope with human carelessness. Not only should we as individuals demand from the source of supply pure food and water, but we should do our share at home to keep them

Tracks of germs left by a fly crawling on a culture in a dish.

pure. Flies and other insects should be prevented from reaching food. Vegetables and fruits must not be eaten in an unripe or half-rotted condition, nor should the latter be canned or preserved. All raw fruits or vegetables that are not protected by the skin should be washed before eating. In general, foods may be made safe to eat by cooking long enough to kill the germs. Milk to be rendered absolutely safe should be pasteurized (so called after Louis Pasteur, the inventor of the process), that is, heated to 160° Fahrenheit for 20 minutes. Ptomaine poisoning is often caused by the growth of bacteria in canned material. These bacteria were not all killed by the cooking, grew, and gave off the poison or ptomaines. Such foods are dangerous, for cooking does not destroy the poison. Meats which have been hung so long as to have an odor, and cold storage meats that appear to be decayed, should be avoided.

Relation of Proper Exercise and Sufficient Sleep to Health. — We are all aware that exercise in moderation has a beneficial effect upon the human organism. The pale face, drooping shoulders, and narrow chest of the boy or girl who takes no regular exercise is too well known. Exercise, besides giving direct use of the muscles, increases the work of the heart and lungs, causing deeper breathing and giving the heart muscles increased work; it liberates heat and carbon dioxide from the tissues where the work is taking place, thus increasing the respiration of the tissues themselves, and aids mechanically in the removal of wastes from tissues. It is well known that exercise, when taken some little time after eating, has a very beneficial effect upon digestion. Exercise and games, especially if a change of occupation, are of immense importance to the nervous system as a means of rest. The increasing number of playgrounds in this country is due to this acknowledged need of exercise, especially for growing children.

Proper exercise should be moderate and varied. Walking in itself is a valuable means of exercising certain muscles, so is bicycling, but neither is ideal as the *only* form to be used. Vary your exercise so as to bring different muscles into play, take exercise that will allow free breathing out of doors if possible, and the natural fatigue which follows will lead us to take the rest and sleep that every normal body requires.

Sleep is one way in which all cells in the body and particularly those of the nervous system get their rest. The nervous system, by far the most delicate and hardest worked set of tissues in the body, needs rest more than do other tissues, for its work directing the body only ends with sleep or unconsciousness. The afternoon nap, snatched by the brain worker, gives him renewed energy for his evening's work. It is not hard application to a task that wearies the brain; it is *continuous* work without rest.

Effect of Alcohol on the Ability to Resist Disease. — Among certain classes of people the belief exists that alcohol in the form of brandy or some other drink or in patent medicines, malt tonics, and the like is of great importance in building up the body so as to resist disease or to cure it after disease has attacked it. Nothing is further from the truth. In experiments on over three hundred animals, including dogs, rabbits, guinea pigs, fowls, and pigeons, Laitenen of the University of Helsingsfors and Professor Frankel of Halle found that alcohol without exception made these animals more susceptible to disease than were the controls.

Use of Alcohol in the Treatment of Disease. — In the London Temperance Hospital alcohol was prescribed seventy-five times in thirty-three years. The death rate in this hospital has been lower than that of most general hospitals. Sir William Collins, after serving nineteen years as surgeon in this hospital, said: —

"In my experience, speaking as a surgeon, the use of alcohol is not essential for successful surgery. . . . At the London Temperance Hospital, where alcohol is very rarely prescribed, the mortality in amputation cases and in operation cases generally is remarkably low. Total abstainers are better subjects for operation, and recover more rapidly from accidents, than those who habitually take stimulants."

Dr. MacNicholl says: "During a period of ten years the Chicago hospitals in which alcohol was employed in pneumonia showed a death rate of twenty-eight to thirty-eight per cent. Non-alcoholic medication during the same period at the Mercy Hospital showed a death rate in pneumonia of less than twelve per cent. . . . The mortality in our hospitals bears a very close relation to the per capita of alcohol prescribed. In the Fordham Hospital, where seventy-two cents per capita of alcohol is prescribed, one out of every eight patients who enter for treatment dies. In the German Hospital, Philadelphia, where forty-three cents per capita of alcohol is prescribed, one of every sixteen patients die. In the Red

Cross Hospital, New York City, where no alcohol is prescribed, one out of one hundred and four patients die."

Dr. S. A. Knopf says: "Alcohol does not cure tuberculosis! Used in excess and injudiciously administered, it surely retards recovery."

Dr. Legrain, senior physician to the asylum Ville Evrard, Paris, declares: "The systematic treatment of chronic tuberculosis by alcohol is apparently a physiological absurdity."

Professor Guttstadt of Berlin publishes statistics showing that in Prussia of every 1000 deaths of men over twenty-five years, 161 are from tuberculosis. Of every 1000 deaths among bartenders, 556 are from tuberculosis; among brewery employees, 345; schoolteachers, 143; physicians, 113; clergy, 76. The 55th annual report of the British Registrar General gives the average death rate of England as 13 per thousand, but among brewers it is 41 per thousand, only four occupations showing a higher rate.

In a paper read at the International Congress on Tuberculosis, in New York, 1906, Dr. Crothers remarked that alcohol as a remedy or a preventive medicine in the treatment of tuberculosis is a most dangerous drug, and that all preparations of sirups containing spirits increase, rather than diminish, the disease.

Dr. Kellogg says: "The grave significance of the effects of alcohol upon living cells can be fully appreciated only when we keep in mind the fact that phagocytosis is the chief means of bodily defense against bacterial disease. It is only through leucocytosis — the migration of leucocytes, and their activity in attacking and destroying bacteria — that recovery from any infectious disease is possible. The paralyzing influence of alcohol upon the white cells of the blood — a fact which is attested by all investigators — is alone sufficient to condemn the use of this drug in acute or chronic infections of any sort."

Experience of Insurance Companies. — The United Kingdom Temperance and General Provident Institution of London insures in two departments, a general section and one for total abstainers. During the sixty years from 1841 to 1901 there were 31,776 whole-life policies in the general or nonabstaining section. These passed through 446,943 years of life, and there were 8947 deaths. In the abstaining section there were 29,094 whole-life policies, passing through 398,010 years of life, with 5124 deaths. If the death rate in the abstaining section had equaled that in the general section, there would have been 6959 deaths instead of 5124, or the mortality

averaged 36 per cent higher in the nonabstaining section than in the abstaining section.

In his article published in the book by Horsley and Sturge, Dr. Arthur Newsholme says: —

"Out of every 100,000 starting at the age of twenty, among the abstainers 53,044 reach the age of seventy, while only 42,109 reach this age in the general experience of a large number of life offices of Great Britain."

> Of 100,000 total abstainers starting at twenty
> 53,044 reach 70 years; 46,956 die before 70 years; and
> of 100,000 moderate drinkers starting at twenty
> 42,109 reach 70 years; 57,891 die before 70 years

In the Scottish Temperance Life Assurance Society, in the twenty years ending 1897, the deaths amounted to 69 per cent of the expected mortality in the general section, while in the total abstainers' section they amounted to only 47 per cent of the expected number. The number of deaths in the general section of the Sceptre Life Association, England, was 80.34 per cent of the expectation in the fifteen years ending 1898, but in the total abstainers' section it was only 56.37 per cent of the expected mortality.

In considering the statistics of the insurance companies, it is well to remember that those insured in the general sections were picked men as well as those in the total abstainers' sections.

In discussing the experience of fraternal societies, Dr. Newsholme gives the following statistics from the report of the Public Actuary of South Australia: —

	Average Mortality Per Cent	Average Sickness in Weeks
Abstainers' Societies	0.689	1.248
Nonabstainers' Societies	1.381	2.317

	Mortality Per Cent of Sick Members	Average Weeks of Sickness per Each Member Sick
Abstainers' Societies	3.557	6.45
Nonabstainers' Societies	6.532	10.91

Attention should be called to the fact that the nonabstainers' societies have many members who are total abstainers, but, unlike the abstainers' societies, they do not refuse to admit

nonabstainers. The number of weeks of sickness in the table refers to the average number of weeks for which the members call upon the sick fund of the society.

The following are rules of individual hygiene as summarized from the Yale Lectures on Hygiene by Professor Irving Fisher, 1906–1907 : —

Air

Keep outdoors as much as possible.

Breathe through the nose, not through the mouth.

When indoors, have the air as fresh as possible —

(*a*) By having aired the room before occupancy.

(*b*) By having it continuously ventilated while occupied.

Not only purity, but coolness, dryness, and motion of the air, if not very extreme, are advantageous. Air in heated houses in winter is usually too dry, and may be humidified with advantage.

Clothing should be sufficient to keep one warm. The minimum that will secure this result is the best. The more porous your clothes, the more the skin is educated to perform its functions with increasingly less need for protection. Take an air bath as often and as long as possible.

Water

Take a daily water bath, not only for cleanliness, but for skin gymnastics. A cold bath is better for this purpose than a hot bath. A short hot followed by a short cold bath is still better. In fatigue, a very hot bath lasting only half a minute is good.

A neutral bath, beginning at 97° or 98°, dropping not more than 5°, and continued 15 minutes or more is an excellent means of resting the nerves.

Be sure that the water you drink is free from dangerous germs and impurities. "Soft" water is better than "hard" water. Ice water should be avoided unless sipped and warmed in the mouth. Ice may contain *spores* of germs even when germs themselves are killed by cold.

Cool water drinking, including especially a glass half an hour before breakfast and on retiring, is a remedy for constipation.

Food

Teeth should be brushed *thoroughly* several times a day, and floss silk used between the teeth. Persistence in keeping the mouth clean is not only good for the teeth, but for the stomach.

Masticate all food up to the point of involuntary swallowing, with the attention on the taste, not on the mastication. Food should simply be

chewed and relished, with no thought of swallowing. There should be no more effort to prevent than to force swallowing. It will be found that if you attend only to the agreeable task of extracting the flavors of your food, Nature will take care of the swallowing, and this will become, like breathing, involuntary. The more you rely on instinct, the more normal, stronger, and surer the instinct becomes. The instinct by which most people eat is perverted through the " hurry habit " and the use of abnormal foods. Thorough mastication takes time, and therefore one must not feel hurried at meals if the best results are to be secured.

Sip liquids, except water, and mix with saliva as though they were solids.

The stopping point for eating should be at the *earliest* moment when one is really satisfied.

The frequency of meals and time to take them should be so adjusted that no meal is taken before a previous meal is well out of the way, in order that the stomach may have had time to rest and prepare new juices. Normal appetite is a good guide in this respect. One's best sleep is on an empty stomach. Food puts one to sleep by diverting blood from the head, but disturbs sleep later. Water, however, or even fruit may be taken before retiring without injury.

An exclusive diet is usually unsafe. Even foods which are not ideally the best are probably needed when no better are available, or when the appetite especially calls for them.

The following is a very tentative list of foods in the order of excellence for general purposes, subject, of course, to their palatability at the time eaten: fruits, nuts, grains (including bread), butter, buttermilk, salt in small quantities, cream, milk, potatoes, and other vegetables (if fiber is rejected), eggs, custards, digested cheeses (such as cottage cheese, cream cheese, pineapple cheese, Swiss cheese, Cheddar cheese, etc.), curds, whey, vegetables, if fiber is swallowed, sugar, chocolate, and cocoa, putrefactive cheeses (such as Limburger, Rochefort, etc.), fish, shellfish, game, poultry, meats, liver, sweetbreads, meat soups, beef tea, bouillon, meat extracts, tea and coffee, condiments (other than salt), and alcohol. None of these should be absolutely excluded, unless it be the last half dozen, which, with tobacco, are best dispensed with for reasons of health. Instead of excluding specific food, it is safer to follow appetite, merely giving the benefit of the doubt between two foods, equally palatable, to the one higher in the list. In general, hard and dry foods are preferable to soft and wet foods. Use some raw foods — nuts, fruits, salads, milk, or other — daily.

The amount of proteid required is much less than ordinarily consumed. Through thorough mastication the amount of proteid is automatically reduced to its proper level.

The sudden or artificial reduction in proteid to the ideal standard is apt to produce temporarily a " sour stomach," unless fats be used abundantly.

To balance each meal is of the utmost importance. When one can trust the appetite, it is an almost infallible method of balancing, but some knowledge of foods will help. The aim, however, should always be — and this cannot be too often repeated — to educate the appetite to the point of deciding all these questions automatically.

Exercise and Rest

The hygienic life should have a proper balance between rest and exercise of various kinds, physical and mental. Generally every muscle in the body should be exercised daily.

Muscular exercise should hold the attention, and call into play will power. Exercise should be enjoyed as play, not endured as work.

The most beneficial exercises are those which stimulate the action of the heart and lungs, such as rapid walking, running, hill climbing, and swimming.

The exercise of the abdominal muscles is the most important in order to give tone to those muscles and thus aid the portal circulation. For the same reason erect posture, not only in standing, but in sitting, is important. Support the hollow of the back by a cushion or otherwise.

Exercise should always be limited by fatigue, which brings with it fatigue poisons. This is nature's signal when to rest. If one's use of diet and air is proper, the fatigue point will be much further off than otherwise.

One should learn to relax when not in activity. The habit produces rest, even between exertions very close together, and enables one to continue to repeat those exertions for a much longer time than otherwise. The habit of lying down when tired is a good one.

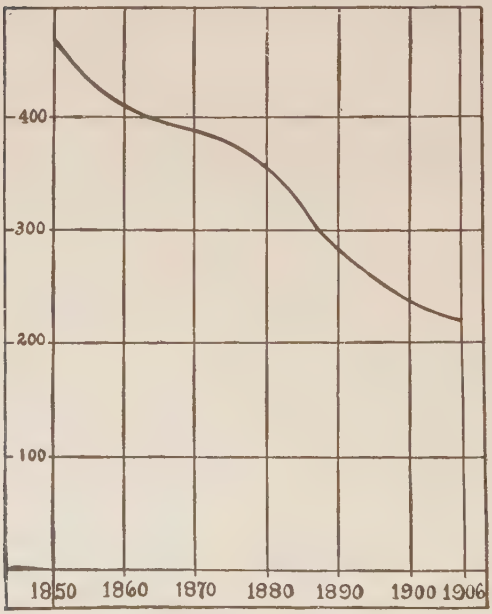
The same principles apply to mental rest. Avoid worry, anger, fear, excitement, hate, jealousy, grief, and all depressing or abnormal mental states. This is to be done not so much by repressing these feelings as by *dropping* or ignoring them — that is, by diverting and controlling the attention. The secret of mental hygiene lies in the direction of attention. One's mental attitude, from a hygienic standpoint, ought to be optimistic and serene, and this attitude should be striven for not only in order to produce health, but as an end in itself, for which, in fact, even health is properly sought. In addition, the individual should, of course, avoid infection, poisons, and other dangers.

Occasional physical examination by a *competent* medical examiner is advisable. In case of illness, competent medical treatment should be sought.

Finally, the duty of the individual does not end with personal hygiene. He should take part in the movements to secure better public hygiene in city, state, and nation. He has a selfish as well as an altruistic motive to do this. His air, water, and food depend on health legislation and administration.

All the foregoing rules are important. The results which may be obtained by following them depend largely on the thoroughness with which they are followed. This is true especially of fresh air and mastication. If all the rules are followed and followed thoroughly, including the one most commonly neglected, — namely, keeping within the fatigue limit, — the average man may reasonably expect to double his length of life, his activity per day, his satisfactions and his usefulness. The laws of "humaniculture" can be depended upon as much as those of agriculture, horticulture, or stock raising.

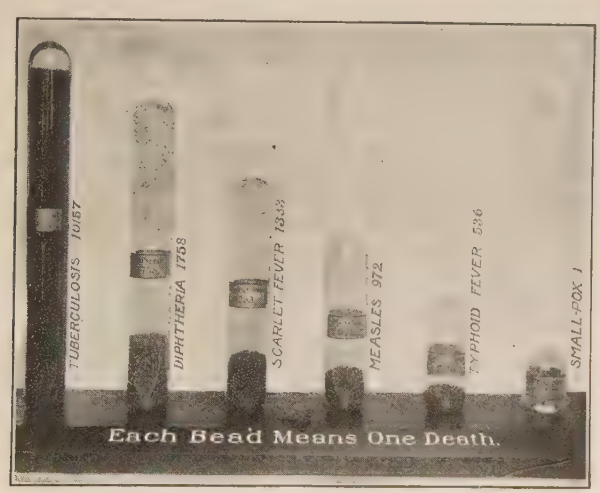
Public Hygiene. — Although it is absolutely necessary for each individual to obey the laws of health if he or she wishes to keep from disease, it has also become necessary, especially in large cities, to have general supervision over the health of people living in a community. This is done by means of a department or board of health. It is the function of this department to care for public health. A list of regulations and laws known as the *Sanitary Code* is given out to the citizens. These regulations concern the care of buildings and plumbing, of the cleanliness of street cars and other public vehicles, the protection and supervision of foods sold, the inspection of our supplies of milk and water, and particularly, the control of disease.



The curve showing a decreasing death rate from tuberculosis. Why do fewer people die from the disease than formerly?

Examples of what public control of disease will do is seen when

we consider the specific case of the disease known as smallpox. In the eighteenth century 5,000,000 people are said to have died from it; one hundred years ago it was exceedingly common in all large cities in this country. To-day an epidemic of smallpox is impossible, thanks to the discovery of vaccination and prompt action by the health department. Tuberculosis at the present time kills more people annually than any other disease, and yet it is believed by sanitary living we will stamp out the disease within fifty years if



Deaths from tuberculosis contrasted with the other contagious diseases in the center of New York in 1908.

we go on at the present rate. Public hygiene is largely responsible for the lessening of deaths from typhoid fever and other diseases which are transmitted through the milk or water supply. It is estimated that pure milk, pure water, and pure air supplied to all would lengthen the average human life in the United States eight years. At the present rate human life is being lengthened about 14 years every century in Massachusetts, 17 in Europe, and 27 per century in Prussia.[1] In India, on the other hand, where little hygiene is known or practiced among the masses of people, the length of life is stationary.

[1] This result is obtained by the saving of the lives of thousands of young children, who now grow to become adults.

Ex-President Roosevelt said in one of his latest messages to Congress: —

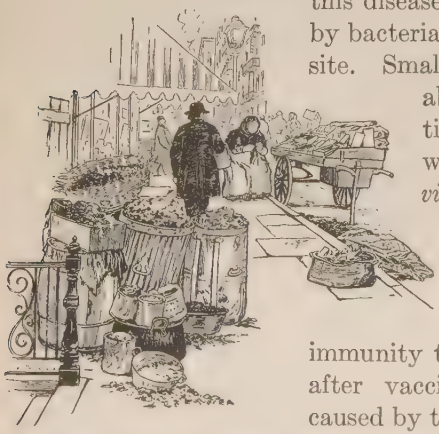
"There are about 3,000,000 people seriously ill in the United States, of whom 500,000 are consumptives. *More than half of this illness is preventable.* If we count the value of each life lost at only $1700 and reckon the average earning lost by illness at $700 a year for grown men, we find that the economic gain from mitigation of preventable disease in the United States would exceed $1,500,000,000 a year. This gain can be had through medical investigation and practice, school and factory hygiene, restriction of labor by women and children, the education of the people in both public and private hygiene, and through improving the efficiency of our health service, municipal, state, and national."

Infectious Diseases and Quarantine. — One of the important means for prevention of the spread of diseases caused by bacteria or Protozoa is by quarantine. The board of health at once isolates any case of disease which may be communicated from one person to another. This is called *quarantine*. No one save the doctor or nurse should enter the room of the person quarantined. After the disease has run its course, the clothing, bedding, etc., in the sick room is fumigated. This is usually done by the board of health. Formaldehyde in the form of candles for burning or in a liquid form is a good disinfectant. The room should be tightly closed to prevent the escape of the gas used, as the object of the disinfection is to kill all the disease germs left in the room.

Immunity. — In the prevention of germ diseases we must fight the germ by attacking the parasites directly with poisons that will kill them (such poisons are called *germicides* or *disinfectants*), and we must strive to make the persons coming in contact with the disease unlikely to take it. This insusceptibility or *immunity* may be either natural or acquired. Natural immunity seems to be in the constitution of a person, and may be inherited. Immunity may be acquired by means of such treatment as the antitoxin treatment for diphtheria. This treatment, as the name denotes, is a method of neutralizing the poison (toxin) caused by the bacteria in the system. It was discovered a few years ago by a German, Von Behring, that the serum of the blood of an animal immune to diphtheria is capable of neutralizing the poison produced by the diphtheria-causing bacteria. Horses are rendered immune

by giving them gradually larger doses of the diphtheria toxin or poison. The serum (or liquid part) of the blood of these horses is then used to inoculate the patient suffering from or exposed to diphtheria, and thus the disease is checked or prevented altogether by the antitoxin injected into the blood.

Vaccination. — Smallpox was once the most feared disease in this country; 95 per cent of all people suffered from it. As late as 1898, over 50,000 persons lost their lives annually in Russia from this disease. It is probably not caused by bacteria, but by a tiny animal parasite. Smallpox has been brought under absolute control by vaccination, — the inoculation of man with the substance (called *virus*) which causes cowpox in a cow. Cowpox is like a mild form of smallpox, and the introduction of this virus gives complete immunity to smallpox for several years after vaccination. This immunity is caused by the formation of a germicidal substance in the blood, due to the introduction of the virus.



A bad condition of the streets, lower East Side, New York.

The Work of the Department of Street Cleaning. — In any city one menace to the health of its citizens exists in the refuse and garbage. The city streets, when dirty, contain countless millions of germs which have come from decaying material, or from people ill with disease. In most large cities a department of street cleaning not only cares for the removal of dust from the streets, but also has the removal of garbage, ashes, and other waste as a part of its work. The practice of putting *open* cans containing ashes and garbage into the street for disposal is an indirect means of spreading disease, for flies breed and germs may thrive there. The street-cleaning department should be aided by every citizen; rules for the separation of garbage, papers, and ashes should be kept. Garbage and ash cans should be *covered*. The practice of upsetting ash or garbage cans is one which no young citizen should

allow in his neighborhood, for sanitary reasons. The best results in summer street-cleaning are obtained by washing or flushing the streets, for thus the dirt containing germs is prevented from getting into the air. The garbage is removed in carts, and part of it is burned in huge furnaces. The animal and plant refuse is cooked in great tanks; from this material the fats are extracted, and the solid matter is sold for fertilizer. Ashes are used for filling marsh land. Thus the removal of waste matter may pay for itself in a large city.

Removal of ashes by department of street cleaning, New York.

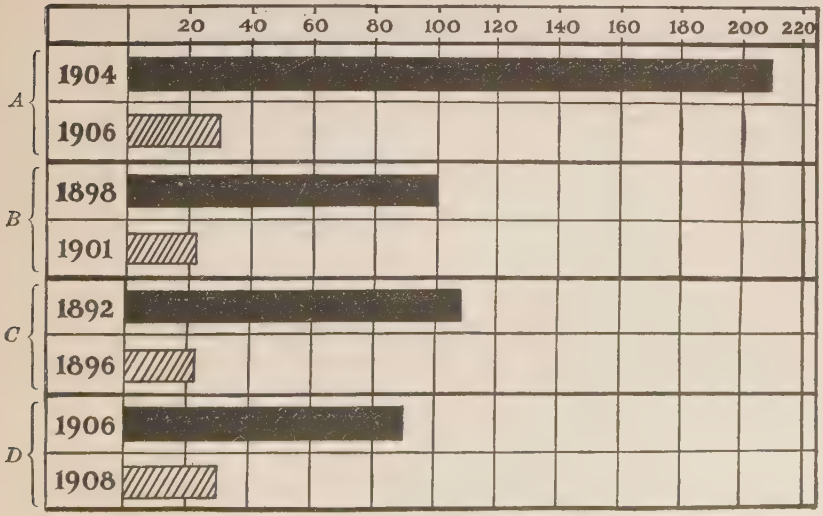
The Necessity of a Pure Milk and Water Supply. — The city of New York is spending hundreds of millions of dollars to bring a supply of pure water to her citizens. Other cities are doing the same. The world has awakened to the necessity of a pure water supply, largely because of the number of epidemics of typhoid which have been caused by contaminated water. Typhoid fever germs live in the food tube, hence the excreta of a typhoid patient will contain large numbers of germs. In a city with a system of sewage such germs might eventually pass from the sewers into a river. Many cities take their water supply directly from rivers, sometimes not far below another large town. Such cities must take many germs into their water supply. Many cities, as Cleveland and Buffalo, take their water from lakes into which their sewage flows. In cities which drain their sewage into rivers and lakes, the question of sewage disposal is a large one, and many cities now have means of disposing of their sewage in some manner as to render it harmless to their neighbors. Filtering such water by means of passing the water through settling basins and sand filters removes about 98 per cent of the germs. The result of drinking unfiltered and filtered water in certain large cities is shown graphically on the following page.

In the country typhoid may be spread by the germs getting into a well or spring from whence the supply of water comes. This

may be avoided by having privies and cesspools some distance from the well and so placed that they will drain *away* from it. Wells should have a cemented cap around the top so as to keep out surface water, as germs rarely live long more than five feet below ground.

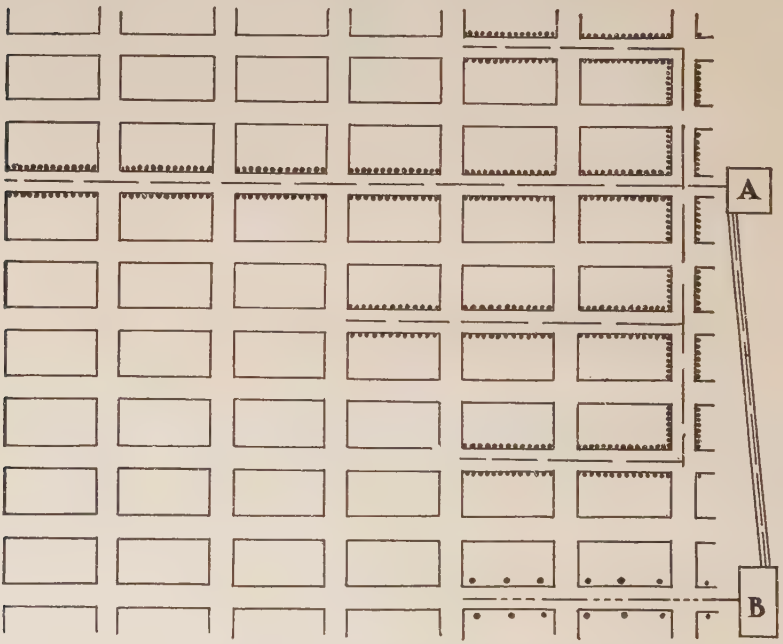
Growth of bacteria in a drop of impure water allowed to run down a sterilized culture in a dish.

Serious outbreaks of typhoid have been traced to contaminated milk supplies. A case of typhoid exists on a farm; the sewage gets into the well from which water is used for the washing of milk cans. Typhoid germs thrive in milk. Thus the milkman spreads disease. The diagram on the following page illustrates a recent epidemic, which was traced to a farm on which was a person having typhoid.



Cases of typhoid per 100,000 inhabitants before filtering water supply (solid) and after (shaded) in *A*, Watertown, N.Y.; *B*, Albany, N.Y.; *C*, Lawrence, Mass.; *D*, Cincinnati, Ohio. What is the effect of filtering the water supply?

Railroads are often responsible for carrying typhoid and spreading it. It is said that a recent outbreak of typhoid in Scranton, Pa., was due to the fact that the excreta from a typhoid patient traveling in a sleeping car was washed by rain into a reservoir near which the train was passing. Railroads are thus seen to be great open sewers. A sanitary car toilet should be provided so that filth and disease will not be scattered over the country.



A diagram to show how typhoid may be spread in a city through an infected milk supply. The black spots in the blocks mean cases of typhoid. *A*, a farm where typhoid exists; the dashes in the streets represent the milk route. *B* is a second farm which sends part of its milk to *A*; the milk cans from *B* are washed at farm *A* and sent back to *B*. A few cases of typhoid appear along *B*'s milk route. How do you account for that?

How the Board of Health fights Typhoid. — Pure water is the first essential in preventing epidemics of typhoid. Health board officials are constantly testing the supply, and, if any harmful bacteria are found, a warning is sent out to *boil* the water. Boiling water at least 10 minutes kills most harmful germs.

The milk supply is also subject to rigid inspection. Milk brought into a city is tested, not only for the amount of cream present to prevent dilution with water, but also for the presence of germs. The cleanliness of the cans, wagons, etc., is also subject to inspection.

"The patients live out of doors."

The cows are also inspected to see if they have tuberculosis, for such cows *might* spread the disease to human beings.

During the summer months many babies die from cholera infantum. This disease is almost entirely spread through impure milk. Flies are largely responsible for the spread of the disease by carrying the germs to milk. Spread of such diseases through milk can only be prevented by careful pasteurization (heating to 160° for 20 minutes). In many large cities pasteurized milk is sold at a reasonable price to poor people, and thus much disease is prevented.

Disease germs of various sorts, typhoid, tuberculosis, pneumonia,

diphtheria, and many others may be transferred through the agency of food. Fruits and vegetables may be carriers of disease, especially if they are sold from exposed stalls or cars and handled by the passers-by. All vegetables, fruits, or raw foods should be carefully washed before using. Spoiled or overripe fruit, as well as meat which is decayed, is swarming with bacteria and should not be used. The board of health has supervision over the sale of fruit, meats, fish, etc., and frequently in large cities food unfit for sale is condemned and destroyed.

How the Board of Health fights Tuberculosis. — Tuberculosis, which a few years ago killed fully one seventh of the people who died from disease in this country, now kills less than one tenth. This decrease has been largely brought about because of the treatment of the disease. Since it has been proved that tuberculosis if taken early enough is curable, by quiet living, good food, and *plenty* of fresh air and light, we find that numerous sanatoria have come into existence which are supported by private or public means. At these sanatoria the patients *live* out of doors, especially sleep in the air, while they have plenty of nourishing food and little exercise. In this way and by tenement-house laws which require proper air shafts and window ventilation in dwellings, by laws against spitting in public places, and in other ways the boards of health in our towns and cities are waging war on tuberculosis.

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Bulletins and Publications of Committee of One Hundred on National Health.
School Hygiene, American School Hygiene Association.

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